PIPE DISTRIBUTION SYSTEMS[1]

By Nicholas S. Hill, Jr.

Part I

A STUDY OF CONSIDERATIONS AFFECTING THE DESIGN OF PIPE DISTRIBUTION SYSTEMS

The occasions on which an engineer is called upon to design a distribution system "de novo" for a city of considerable size are very rare. The problem usually presented to him for solution is the design of extensions or reinforcements in an existing system with a view of improving existing pressure conditions, particularly at times of fire.

Before entering either upon the design of a new distribution system or upon the preparation of plans for the improvement of an existing one, the engineer will be called upon to consider local conditions and decide a number of preliminary questions which will affect the problem which he undertakes to solve, and hence the subsequent design.

PRELIMINARY DATA

One of the first steps preliminary to the study of a distribution system is to secure or prepare a base map of the community to be served. If possible to secure, the map should show the city and ward boundaries; present and proposed street lines, and the location of railroads and street railways. It is desirable also to obtain a contour map indicating relative elevations in the city and its environs, and the designer should have, either through the medium of a contour map or from other sources, so that the information can be added to the base map, knowledge of the elevation at street intersections. Information to be added to base maps thus secured should include the location of railroad water tanks, large industrial plants, commercial and business sections, and large fire hazards.

[1] Read and discussed at the Philadelphia convention, and now published, in revised form, for the first time. Open for discussion at the Cincinnati convention or by letter.

One base map should also be used for the purpose of showing the streets which contain improved pavements or other structures which will add to the cost of pipe laying.

In problems involving the improvement of an existing system, a map should be prepared showing the location and size of existing mains exceeding 8 inches in diameter, as well as the location of hydrants, pumping stations, filter plants, distributing reservoirs, standpipes, water tanks and towers, and the like.

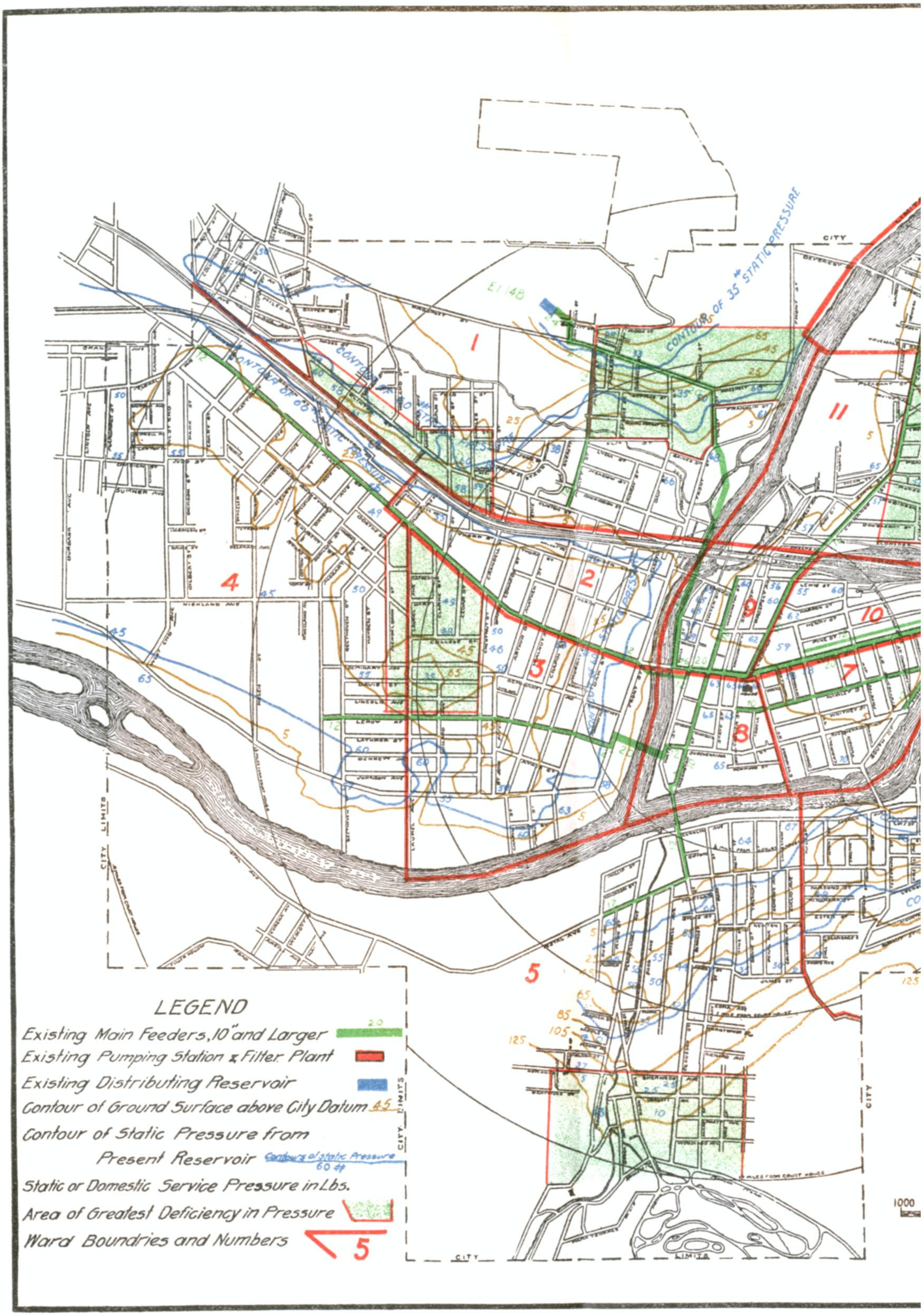
Maps Nos. 1 and 2 presented herewith contain the more important data which should be made available in this form.

In addition to the data available in the form of maps, the designer should secure by local inquiry, inspection, or test, certain statistical data relating to the existing plant, including the capacity of pumping stations and equipment, filter plants, reservoirs, and critical elevations in and about the same; steam and water pressures which are and may be carried at the existing pumping stations; weight, average age, and interior condition of cast iron pipe in the existing distribution system; number of service taps and meters in use; population and water consumption statistics.

He should also have before him the results of tests made on existing hydrants, showing the pressures which obtain in various parts of the community on the date of the design, under both fire and ordinary domestic service conditions, and he should possess a general familiarity with the density and character of the dwellings in different parts of the city.

FUTURE PERIOD CONSIDERED

After having secured or prepared the necessary maps and obtained the necessary data, the engineer must consider and decide upon the future period for which the contemplated improvements are to serve without duplication or enlargement. This period will bear no relation to the useful life of cast iron pipe, which depends largely on the service for which it is used and may exceed a hundred years. It would manifestly be impossible to predict the amount or direction of a city's growth for so long a period as a hundred years with any degree of certainty. It is possible, however, to predict with sufficient accuracy, both the extent and distribution of population growth, upon which the future demand for water will in great measure depend, for a period of twenty to thirty years to come.


LEGEND
Existing Main Feeders, 10" and Larger
Existing Pumping Station & Filter Plant
Existing Distributing Reservoir
Contour of Ground Surface above City Datum
Contour of Static Pressure from Present Reservoir
Contours of static Pressure 60 #
Static or Domestic Service Pressure in Lbs.
Area of Greatest Deficiency in Pressure
Ward Boundries and Numbers
CONTOUR OF 35 # STATIC PRESSURE
CONTOUR OF 60 # STATIC PRESSURE
CITY LIMITS
E1.148
1
2
3
4
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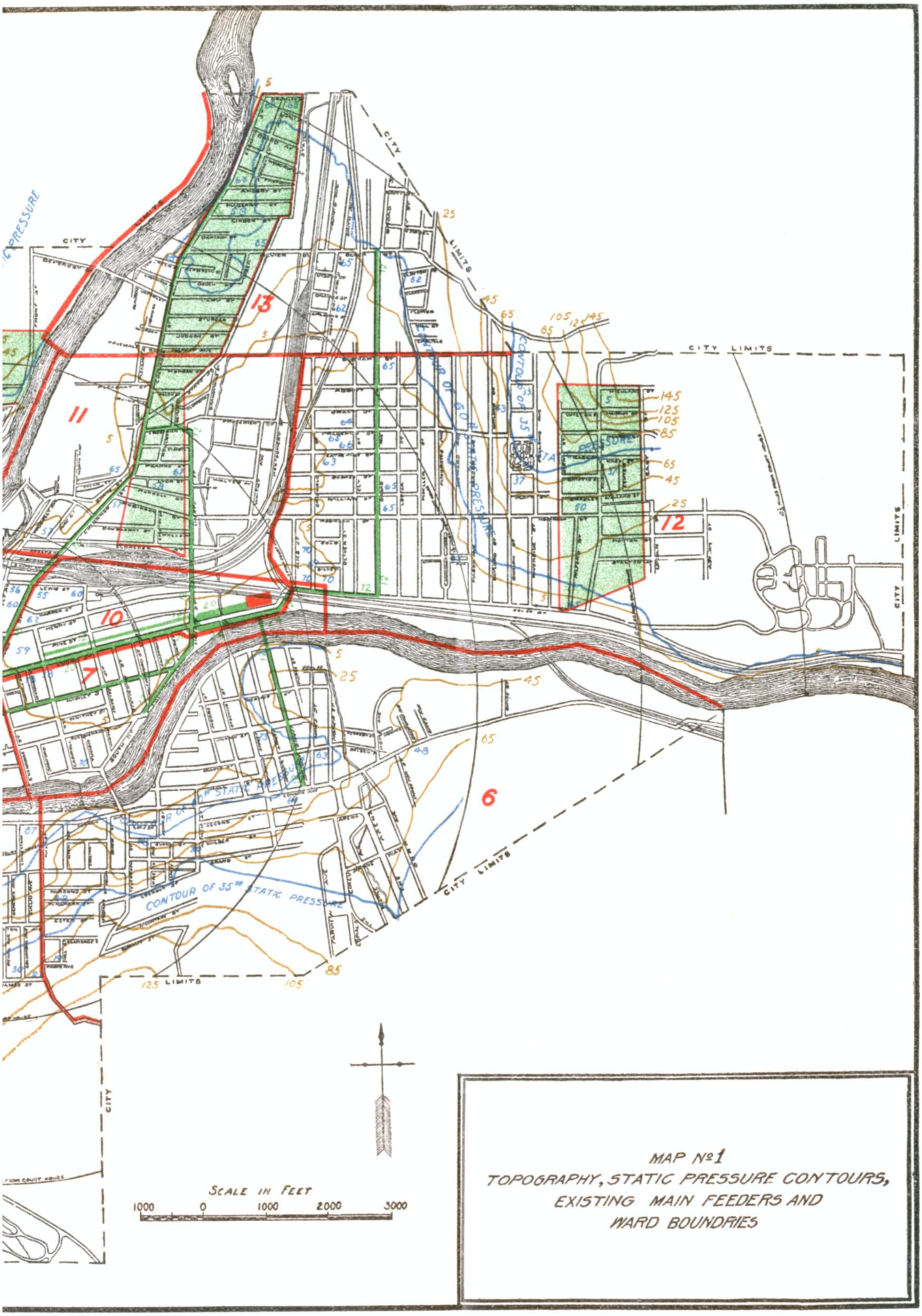
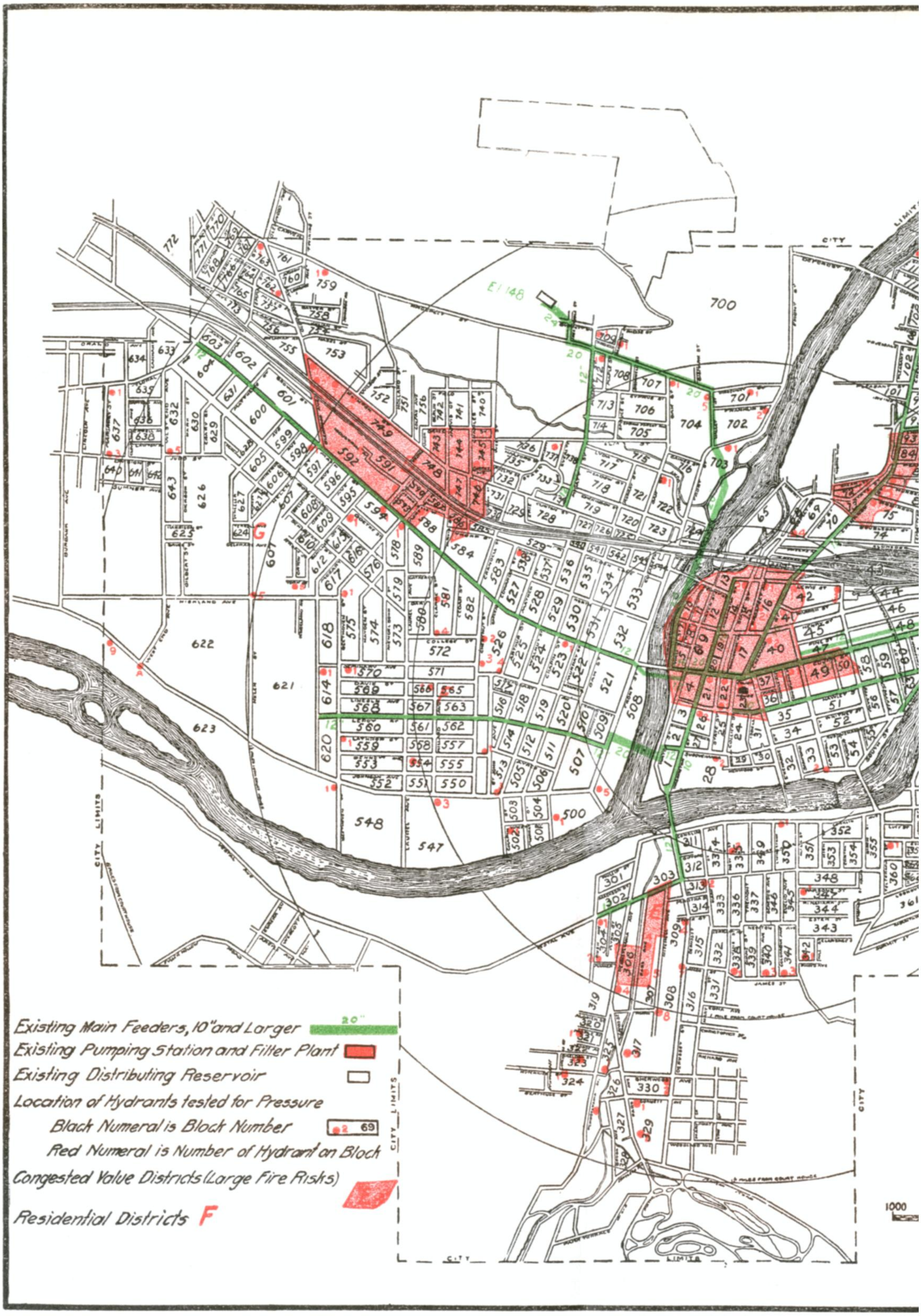
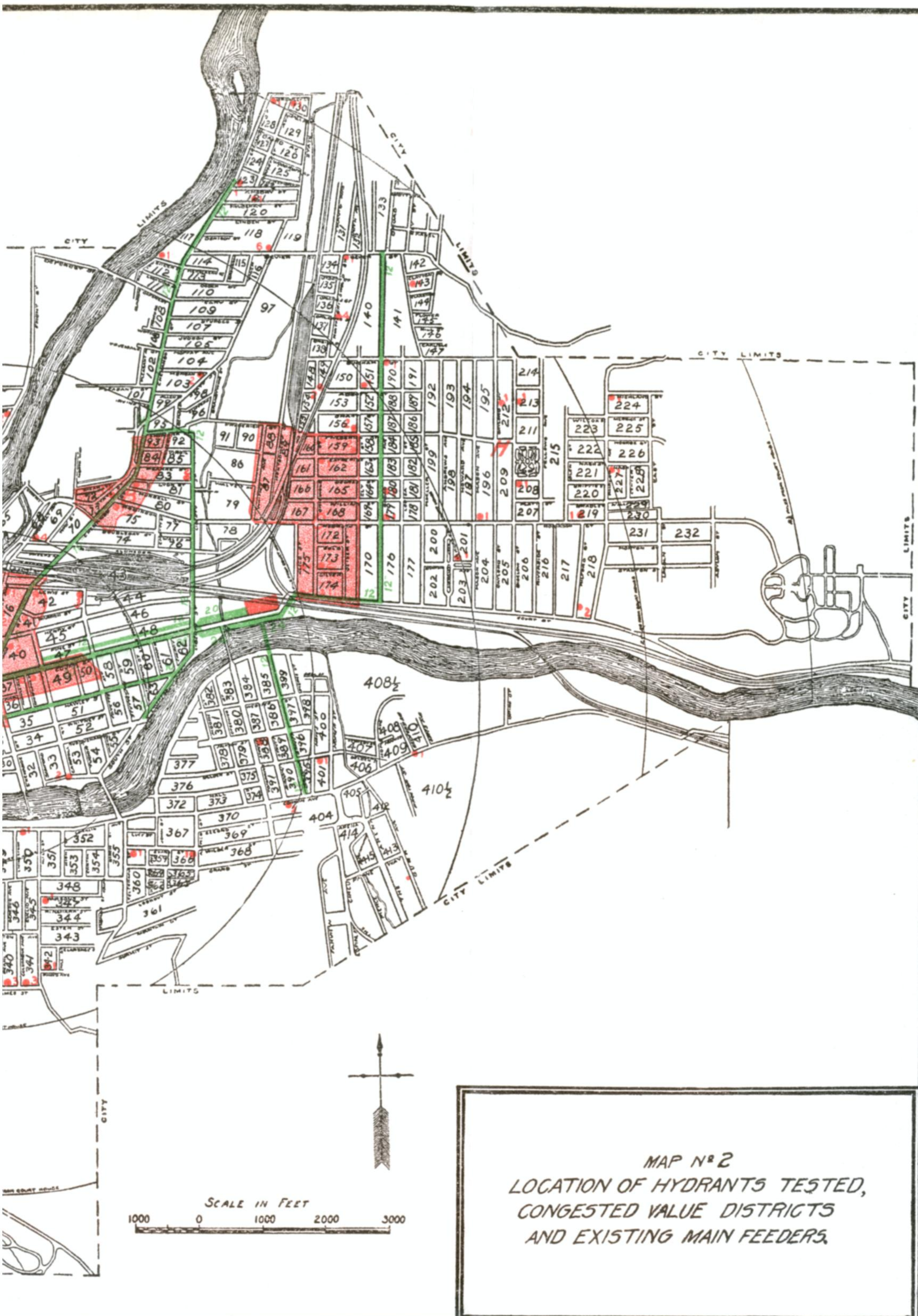


MAP No 1
TOPOGRAPHY, STATIC PRESSURE CONTOURS,
EXISTING MAIN FEEDERS AND
WARD BOUNDRIES


Existing Main Feeders, 10" and Larger
20"
Existing Pumping Station and Filter Plant
Existing Distributing Reservoir
Location of Hydrants tested for Pressure
Black Numeral is Block Number
2 69
Red Numeral is Number of Hydrant on Block
Congested Value Districts (Large Fire Risks)
Residential Districts F
CITY LIMITS
1000



MAP No 2
LOCATION OF HYDRANTS TESTED,
CONGESTED VALUE DISTRICTS
AND EXISTING MAIN FEEDERS.

The reasons for predicating estimates on results which are expected to obtain so far in the future are not that one can undertake to forecast the future with mathematical exactness even for this limited period, but rather because it is the safest and most rational way in which to make reasonable provision for future needs.

Failure to make such provision frequently results in a high capital investment in mains. It is cheaper to lay a main which is too large for present needs than to lay one which must be reinforced within a few years. To show the expense which a company or city incurs by pursuing such a policy. Table No. 1 is presented, which shows the comparative cost of different pipe sizes to give the same service.

The costs given in the table do not and, of course, can not take into consideration the damage to improved streets, and the additional cost of maintaining them, which results from continual tearing up, nor can they take into account the inconvenience, annoyance and the disturbance of traffic which results from repeated removal of the street surface. They further do not include the additional cost of repairs due to the increased main mileage which results from duplication of mains and the increased liability of having to excavate for repairs, nor any consideration of the enhanced pumping costs ensuing from greater main leakage resulting from an increase in the number of pipe joints. The table clearly shows that even where the period of usefulness of the first main laid is eighteen out of twenty-six years, the saving in favor of two mains in most cases is not sufficient to offset the other losses incurred.

POPULATION

Having determined upon the future period to be considered, the next question to arise will be the probable future population of the community to be served. All estimates of future population are based to a greater or less extent upon past growth. Proper regard must be had, however, for special conditions which have tended abnormally to accelerate or retard the rate of growth prior to the date of the design so that proper allowance may be made in the assumed or computed future rate of increase. The percentage growth in communities generally decreases as the population increases, although the total annual increase may be greater in each successive year. It is not always safe, therefore, to apply percentages based on past growth to estimates of the future growth. It has been

TABLE No. 1

Comparative cost per foot, different pipe sizes to give same service

DIAMETER OF PIPE REQUIRED TO SUPPLY THE SERVICE FOR PERIOD OF 26 YEARS	NUMBER AND SIZE OF SMALLER PIPES REQUIRED TO GIVE SAME SERVICE AS SINGLE PIPE OPPOSITE IN COL. (1)	INITIAL COST, CLASS C PIPE, @ $25.00 PER TON IN MEDIUM DIGGING WITH LABOR @ $1.75 PER 10 HR. DAY		ASSUMED NUMBER OF YEARS DURING WHICH A SINGLE PIPE OF DIAMETER GIVEN IN COL. (2) WILL SUFFICE	RELATIVE ANNUAL COSTS PER FOOT UNDER FOLLOWING PLANS						CAPITALIZED ANNUAL COST				SAVING IN FAVOR OF PLAN 1,—THE IMMEDIATE INSTALLATION OF LARGER PIPE	
					Plan 1 Immediate installation of single pipe of size given in col. (1)			Plan 2 Immediate installation of single pipe of size given in col. (2) to be followed after expiration of period given in col. (5) by installation of second pipe of same size			Plan 1	Plan 2				
		Single pipe of diameter given in col. (1)	Single pipe of diameter given in col. (2)		Interest on initial cost @ 5 per cent	Annuity required to amortize capital investment at end of 70 year life @ 4 per cent	Total annual cost per foot	Interest on initial cost of one pipe @ 5 per cent	Annuity required to amortize capital investment at end of 70 year life @ 4 per cent	Total annual cost per foot of one pipe	Total annual cost per foot as given in col. (8) capitalized at 5 per cent	Total annual cost per foot of first pipe as given in col. (11) capitalized @ 5 per cent	Present value of total annual cost per foot of second pipe as given in col. (11) when capitalized @ 5 per cent	Total	Amount in dollars per foot	In per cent of cost of plan 1
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
					= (3) ×.05	= (3) ×.00274	= (6) + (7)	= (4) ×.05	= (4) ×.00274	= (9) + (10)	= (8) ÷.05	= (11) ÷.05	=(11)÷.05 reduced to present value	= (13) + (14)	= (15) − (12)	= (16) ÷ (12)
inches	*inches*	$	$		¢	¢	¢	¢	¢	¢	$	$	$	$	$	%
24	2.05–18	4.61	2.87	6	23.05	1.26	24.31	14.35	0.79	15.14	4.86	3.03	2.26	5.29	0.43	8.8
				12	23.05	1.26	24.31	14.35	0.79	15.14	4.86	3.03	1.69	4.72	−0.14	−2.9
				18	23.05	1.26	24.31	14.35	0.79	15.14	4.86	3.03	1.26	4.29	−0.57	−11.7
16	2.05–12	2.42	1.59	6	12.10	0.66	12.76	7.95	0.44	8.39	2.55	1.68	1.25	2.93	0.38	14.9
				12	12.10	0.66	12.76	7.95	0.44	8.39	2.55	1.68	0.94	2.62	0.07	2.7
				18	12.10	0.66	12.76	7.95	0.44	8.39	2.55	1.68	0.70	2.38	−0.17	−6.7
8	2.05–6	0.96	0.69	6	4.80	0.26	5.06	3.45	0.19	3.64	1.01	0.73	0.54	1.27	0.26	25.7
				12	4.80	0.26	5.06	3.45	0.19	3.64	1.01	0.73	0.41	1.14	0.13	12.9
				18	4.80	0.26	5.06	3.45	0.19	3.64	1.01	0.73	0.30	1.03	0.02	2.0

the practice in the office of the author of this paper not only to base estimates of future growth upon the past increase of population, but to check such estimates by comparing the estimated growth during, say, the next twenty years with the past growth of similarly located towns whose population twenty years ago was about equal to the present population of the town under consideration.

Several methods of estimating future growth may be used. They may be designated as follows: arithmetical progression method; comparative method; incremental increase method; geometrical progression method.

Arithmetical progression method

This method is applicable only in rare cases and almost uniformly produces estimates which are too low. The method, as its name implies, involves the assumption that the future rate of increase from year to year will be constant, and the same as has obtained in the past, or for some period which may be selected at the choice of the computor.

Comparative method

The comparative method involves the selection of cities, similarly situated, whose population, say twenty years ago, was practically the same as the present population of the town under study. The past growth of such towns is then taken fairly to represent the probable future growth of the one in question.

Incremental increase method

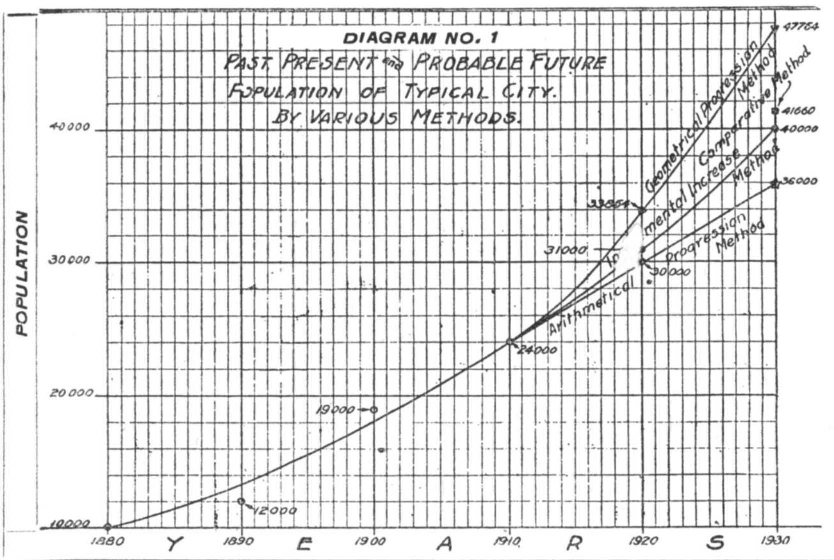
By the incremental increase method, the population of a town by decades is ascertained as far back as records have been kept. The actual gross increase in population from decade to decade is determined. Then the increase in the increase is determined, or the increment of increase for each decade. The actual increase as determined for each decade is averaged, and also the increment of increase. In making the estimates of future population, the population at the end of the first future decade is obtained by adding to the present population the average increase plus the average increment per decade thus found, and the future population at the end of the second decade by adding to the estimated population at the end of the first future decade, the average increase, plus twice the average increment, and so on.

Geometrical progression method

The geometrical progression method involves the determination of the compound rate at which the population of a city has increased in the past, then applying this compound rate to the present population, to determine the future growth.

Comparison of methods

The curves on Diagram No. 1 give the results of applying each of the four methods outlined to the population of a typical



city. The population between 1880 and 1910 as expressed by the curve is that returned by the census. The populations from 1910 to 1930 are those computed by the four methods.

It will be noted that the incremental increase method is about a mean of the several methods, and experience has shown that it frequently falls in this way in towns of normal growth. No single method, however, is applicable to all conditions and judgment must be exercised in estimating future population.

DISTRIBUTION OF POPULATION

The preceding methods are those commonly employed in estimating the future population of the community as a whole, but it

is desirable to subdivide the total population by districts in order that the size of the pipe intended to supply individual localities may be proportioned intelligently.

Whereas the commercial and manufacturing use of water and the water required for fire service are practically independent of the distribution of population, the domestic and public demand for water follows the distribution of population very closely and, therefore, a study of the distribution of population enables one to make a reasonably intelligent estimate of the probable local demands for water for the last two purposes named. After the local demand for water required for domestic and public uses has been determined through the study of population distribution, the water required for manufacturing, commercial and fire purposes in the sub-divisions used for localizing the domestic and public supply may be added from knowledge of the specific use of water for commercial, manufacturing and fire purposes in those districts.

A distribution system to be economically built must be designed to meet the conditions of some future year. In this year the distribution of population may, and usually will, be quite different from the distribution on the date of design. On the date of design some districts may be fully built up, and it would obviously be erroneous to assume that the future domestic and public water requirements in such districts will increase in the same proportion as for growing districts, or as for the city as a whole. It is possible, however, for the designer to establish a reasonable figure representing the probable density of population in any section in the city considered. He may then in apportioning the total future population by districts avoid exceeding this figure in any built up district, and by the exercise of a little judgment and with a knowledge of the local conditions, apportion the balance of the total growth to the more sparsely settled districts and thus obtain a fairly accurate future distribution of population, and hence of domestic and public water consumption.

Subdivision by wards is convenient for the purpose of apportioning local consumption in different districts and may be made without difficulty as the ward populations are usually given in the census returns.

Where ward boundaries include large areas, a further subdivision may be made, if desired, by estimating the population by registration districts. Knowing the total registration in a given city or

ward in a given year, and the population in the same year, a ratio may be established between the population and the number of registered voters. By applying this ratio to the number of registered voters in a given registration district, its population may be closely approximated. This refinement, however, is not usually necessary.

CONSUMERS

Having decided upon the probable rate of growth and distribution of future population in the territory to be supplied, it will be necessary before proceeding with estimates of domestic and public water consumption to determine the future population which will probably require to be served with water. The percentage of the total population actually connected with the public supply seldom exceeds 90 to 95 per cent, and may be much less than this, depending upon local conditions and upon the individual characteristics of the community. The desirability of basing estimates of future domestic consumption upon the probable number of water consumers, rather than upon the probable total population is, therefore, apparent.

With new installations there is usually a period of rapid growth extending over several years in which the per cent which the number of consumers bear to the total population increases rapidly from zero to a comparatively large figure. Following this development period it is not uncommon for the per cent of consumers to increase at a gradually retarded rate until 90 to 95 per cent are connected with the mains.

In designing extensions to existing systems it usually is possible to ascertain the number of consumers in present and past years, to establish the ratio between the number of these consumers and the total population, and from a study of the past in the light of knowledge of local conditions to forecast with sufficient accuracy the probable future relation between consumers and population. With this relation fixed the number of future consumers may be estimated from the previously estimated future population.

The number of actual consumers in any past year usually may be estimated most satisfactorily by ascertaining the number of service taps, or first connections, carried on the books of a company, and applying to this number a factor representing the average population per tap or per house in the community considered. In small

cities and in suburban communities this factor will usually be in the neighborhood of 5, though it may in rare instances be as low as 3, and in cities large enough to contain many apartment or tenement houses will be much greater.

The ratio between total population and the number of registered voters may sometimes be useful in determining the proper factor to use in a given community where most of the houses are occupied by not more than one family, while in the larger cities the establishment of the ratio will not be so important since in these the number of consumers will usually comprise a very large percentage of the population, and may be estimated directly.

In designing entirely new systems, the designer will be obliged to assume the probable per cent of the total population which will be served in future years, though he may be guided in forming this judgment by his knowledge of local conditions and by the values known to obtain in communities and under conditions similar to those which he has under consideration.

WATER CONSUMPTION

The next important element affecting the design of a distribution system is the average or normal quantity of water required to be delivered therethrough, and the fluctuations or variations from the normal which may be anticipated from various causes. For the sake of clearness, we will first discuss the average or normal demands and then the fluctuations which may occur.

Average or Normal Consumption of Water

The normal water consumption may be divided into four components:

a. Domestic consumption.

b. Water required for municipal and public purposes, including fire service.

c. Industrial and commercial use.

d. Water unaccounted for.

The relative importance of each component varies widely with the character and size of a community. In small villages the quantity of water required for domestic use, as compared with the quantity which the mains must deliver in time of fire, will be so small as to be almost neglible. In large cities, the reverse will be true,

while in some places the requirements for railroad or industrial uses may greatly outweigh the ordinary domestic and fire service requirements. These facts are well illustrated by Table No. 2. The maximum of the several demands may occur simultaneously, or the maximum of one or more may coincide with the minimum or average of one or more of the others.

TABLE No. 2

Relation between commercial and industrial consumption; water consumed for domestic and public purposes and wasted; and maximum fire demands in various communities

YEAR TO WHICH DATA APPLIES	COMMUNITY	POPULATION	RATE OF CONSUMPTION PER CAPITA						
			TOTAL	DOMESTIC AND PUBLIC PURPOSES AND WASTE		COMMERCIAL AND INDUSTRIAL		MAXIMUM FIRE DEMAND FREEMAN'S MINIMUM	
				Gallons daily	Per cent of total	Gallons daily	Per cent of total	Gallons daily	Per cent of total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1906	East Greenwich, R. I.	3,750	68.6	30.4	44.3	38.2	55.7	384.0	559.0
1906	Patchogue, L. I.	3,800	112.0	43.0	38.4	69.0	61.6	384.0	342.8
1909	Rochester and Lake Ontario Water Company..	7,100	420.2	113.4	27.0	306.8	73.0	253.0	60.2
1913	Woodhaven, L. I.	30,000	66.5	57.9	87.1	8.6	12.9	120.0	180.4
1911	Jamaica, L. I.	42,000	95.9	88.8	92.6	7.1	7.4	103.0	107.4
1908	Boston, Mass[1]	643,810	153.0	125.3	81.9	27.7[2]	18.1	35.8	23.4

[1] *Journal New England Water Works Association,* Vol. 27, No. 1, p. 102.
[2] Meter only.

Domestic Consumption

The quantity of water required for domestic purposes is a function of the number of consumers, although very marked differences are observable in different communities in the actual consumption of water per consumer for domestic purposes, which, after making all due allowance for the presence or absence of meters, are indicative of marked characteristic demands in the individual community for the legitimate use of water for domestic purposes.

Table No. 3 gives in column 5, the domestic consumption of water per consumer per day in various places. The figures as given have

TABLE No. 3

Data relating to consumption of water for domestic and public purposes

NAME OF PLACE OR COMPANY	TOTAL POPULATION CENSUS OF 1910	NUMBER OF DOMESTIC SERVICES MEASURED	ESTIMATED NUMBER OF DOMESTIC CONSUMERS MEASURED	DOMESTIC CONSUMPTION GALLONS DAILY PER CONSUMER	FREE CONSUMPTION PUBLIC PURPOSES. GALLONS DAILY PER CAPITA
(1)	(2)	(3)	(4)	(5)	(6)
Massachusetts:					
Metropolitan Water District of Boston	1,022,230		53799	33.0	7.11
Brockton[2]	56,878			15.5	3.00
Brookline	27,792				13.05
Chelsea	32,452		13937	26.1	
Everett	33,484		395	33.1	
Fall River	119,295				12.79
Lawrence[3]	85,892			17.0	5.00
Malden	44,484		37994	17.6	
Quincy	32,642		8391	25.6	
Revere	18,219		938	36.6	
Somerville	17,236		26234	25.6	
Swampscott	6,204		2871	34.7	
Watertown	12,875		11299	16.7	
Worcester	145,986		3716	44.0	
Rhode Island:					
East Greenwich	3,420		3420	30.4	
Woonsocket	38,125				5.57
Connecticut:					
Hartford[2]	98,915			30.0	5.00
New York:					
Canandaigua	7,217				12.25
Elmira	37,176	2124	12107	19.6	
Geneva	[4]14,000	2481	12500	20.0	
Patchogue	3,824		3824	43.0	
Syracuse[3]	137,249			31.0	18.00
Yonkers	79,803			[1]20.0	5.00
New Jersey:					
East Orange	34,371	3545	18350	58.5	2.00
Montclair	24,426			35.0	
Pennsylvania					
Harrisburg[3]	64,186			30.0	5.00
Pennsylvania Water Co.		2000	10000	21.4	

[1] Report of Water Board, 1904.
[2] Journal of N. E. W. W. Ass'n., March, 1913.
[3] Superintendents' Estimate.
[4] Local Estimate.

TABLE No. 3—Continued

NAME OF PLACE OR COMPANY	TOTAL POPULATION CENSUS OF 1910	NUMBER OF DOMESTIC SERVICES MEASURED	ESTIMATED NUMBER OF DOMESTIC COMSUMERS MEASURED	DOMESTIC CONSUMPTION GALLONS DAILY PER CONSUMER	FREE CONSUMPTION PUBLIC PURPOSES. GALLONS DAILY PER CAPITA
(1)	(2)	(3)	(4)	(5)	(6)
Pennsylvania—*Continued*					
Pittsburgh	533,905	390	1950	35.0	
Vicinity of Pittsburgh		4801	24005	23.0	
Six Other Places in Vicinity of Pittsburgh		17222	86110	20.0	
Ohio:					
Cincinnati	363,591	8245	65960	58.8	7.00
Illinois:					
Peoria	66,950		744	52.0	
Louisiana:					
New Orleans	339,075			35.0	

been obtained from different sources and largely from the Report of the Committee on Water Consumption of the New England Water Works Association as published in the *Journal* of that Association for March, 1913. It is seen from the table that the per consumer consumption of water for domestic purposes in the places listed varies between 15.5 gallons and 58.5 gallons, or by about 360 per cent. It is important that a designer bear this fact in mind and not attempt to force town A to struggle along on 20 gallons per capita for domestic consumption because town B, a thousand miles away, is able to do so.

Water Required for Municipal and Public Purposes

The water required for free public purposes is also given on the preceding table and varies between 2 and 18 gallons daily per capita. Probably an average allowance of 10 gallons daily per capita will be safe in providing for a new system of mains or for reinforcements to an existing system. Although the quantity of water required for these purposes is more properly a function of the total population in the territory supplied than of the number of water consumers in that territory, in most instances no serious error will be introduced by estimating it on the basis of the number of gallons daily required per consumer.

The water consumed for fire purposes is included in the amounts given for free public purposes, but to consider the requirements for fire fighting as a percentage of total consumption, or in gallons per capita or per consumer is grossly misleading for the reason that this fire service comes as a peak load, at long intervals and lasting for but short periods. When these peak loads occur, the demands for fire service may and do, in small communities, represent a quantity often as great, or greater than, the total average daily demand for water, so that special estimates must be made for the purpose of determining the maximum fire draft under given conditions in order properly to design the distribution system. Such estimates fall in the category of fluctuations rather than average demand, and will be estimated separately.

Industrial and Commercial Use

So far as the industrial and commercial consumption is concerned, the ratio of the demand for this purpose to the total demand varies so radically in different places, depending upon the extent of the commercial and industrial interests, that it is not possible to give figures representing a proper allowance for it. It is necessary, in each individual instance, to determine the amount of water at present used for such purposes. This is one of the unknown factors that can be ascertained only by a local survey. The range of consumption for industrial and commercial purposes is from zero in suburban residential districts to 80 or 100 gallons per capita in large manufacturing centers where the processes employed create a heavy demand for water. Even after the present quantity of water used for industrial and commercial purposes has been ascertained by survey there will remain the difficulty of forecasting what this quantity will be in the future as the growth in these requirements frequently bears a rather indefinite relation to the growth of population. It may sometimes be desirable, especially in the case of railroads and of very large industrial concerns, to make individual forecasts of their future needs, basing the judgment upon knowledge of local conditions, inquiries made of the owners or officers of the various companies, etc. In many instances, however, it will be safe to assume that the growth in the requirements of existing industrial and commercial concerns will increase in the same ratio as the population.

In whatever way the future needs of these existing concerns is estimated, some additional allowance should be made for plants which are not extant at the date of the design.

In some instances it may be necessary to take account of the manner in which the daily railroad, industrial and commercial use of water is distributed over the twenty-four hours. If an industrial plant using 500,000 gallons of water per day operates only twelve hours out of the twenty-four, its effective consumption, so far as the required main carrying capacity is concerned, will be at the rate of 1,000,000 gallons per day. As was the case with the fire service flows, however, these estimates fall in the category of fluctuations rather than of average demand and should be estimated separately.

Water Unaccounted for

The water unaccounted for includes that wasted. The water wasted varies materially in different communities, probably, in general, between the limits of 20 per cent and 40 per cent of the total water supplied. The water unaccounted for and wasted may be divided into:

Metered Supplies	*Unmetered Supplies*
1. That unaccounted for through measurement by plunger displacement of pumps where no allowance is made for slip.	1. That unaccounted for through measurement by plunger displacement of pumps where no allowance is made for slip.
2. That lost through leaky mains and services.	2. That lost through leaky mains and services.
3. That unaccounted for through under-registration of meters.	3. That lost through defective plumbing and house piping.

The pump slippage is a variable quantity, varying from 3 per cent in the best type of pumps which are well maintained, to 65 per cent in pumping engines which are not properly cared for. It is exceedingly common to find a slippage of 10 to 20 per cent in the ordinary pumping station.

The loss of water through mains and services depends upon the care and skill with which the distribution system was installed, the amount of attention which is given to the maintenance of the dis-

tribution system, and upon the relation of main mileage to the total consumption. In general, it may be said to vary between 15 per cent and 30 per cent of the total consumption.

Table No. 4 gives the results of leakage tests on carefully laid cast iron pipe from 4 inches to 36 inches in diameter. It indicates that an average main leakage of 100 gallons per mile per inch of diameter may be expected even in new and unusually well constructed systems. In a system containing 100 miles of pipe averaging 8 inches in diameter this would mean a minimum leakage from mains alone of 80,000 gallons daily, or possibly 5 per cent of the total consumption. In the average system it will be considerably more than this.

TABLE No. 4

Results of leakage tests on cast iron pipe

CITY	SIZE OF PIPE INCHES	LENGTH OF PIPE TESTED FEET	NUMBER OF TESTS MADE	AVERAGE LEAKAGE GALLONS DAILY PER MILE PER INCH OF DIAMETER	PRESSURE UNDER WHICH TEST WAS MADE POUNDS
(1)	(2)	(3)	(4)	(5)	(6)
Akron, Ohio	4	717	1	23	66 to 152
Reported by E. G. Brad-	6	31,066	34	66	66 to 152
bury, *Engineering Record,*	8	6,882	6	42	66 to 152
Volume 65, page 432	10	5,123	5	81	66 to 152
	12	9,704	8	102	66 to 152
	16	8,792	11	135	66 to 152
	20	8,389	10	69	66 to 152
	24	3,358	3	69	66 to 152
	30	14,445	8	82	66 to 152
Total or Average		88,476	86	83.4	66 to 152
Columbus, Ohio Reported by J. H. Gregory, *Engineering News,* Volume 72, page 725	36	16,940	3	422	110

Table No. 5 fairly illustrates the water unaccounted for in cities having metered supplies.

An allowance of from 3 to 6 per cent should be made for under registration of meters.

TABLE No. 5

Water unaccounted for in cities with metered supplies

CITY	PER CENT METERED	WATER UNACCOUNTED FOR	
		PER CENT	GALLONS PER DAY PER MILE OF PIPE
(1)	(2)	(3)	(4)
Attleboro, Mass.	(a) 100	53.0	—
Brockton, Mass.	90	32.3	6,200
Fall River, Mass.	96	21.5	10,000
Harrisburg, Pa.	(b) 75±	21.0	—
Hartford, Conn.	(b) 99	39.0	—
Lawrence, Mass.	(b) 87	29.0	—
Madison, Wis.	(a) 97	69.0	—
Needham, Mass.	(a) 95	75.0	—
North Attleboro, Mass.	(a) 100	55.0	—
Providence, R. I.	90	30.0	13,400
Ware, Mass.	100	39.8	11,200
Watertown, Mass.	(a) 94	47.0	—
Wellesley, Mass.	100	41.5	3,450
Winchendon, Mass.	(a) 97	55.0	—
Woonsocket, R. I.	87	23.0	4,370
Worcester, Mass.	94	46.5	20,800
Yonkers, N. Y.	100	45.7	23,340

(a) Data obtained from Table No. 11, p. 136, *Journal New England Water Works Association*, 1907. Paper by W. S. Johnson.

(b) Data obtained from Report of Mr. James H. Fuertes to Merchants Association, New York, 1906.

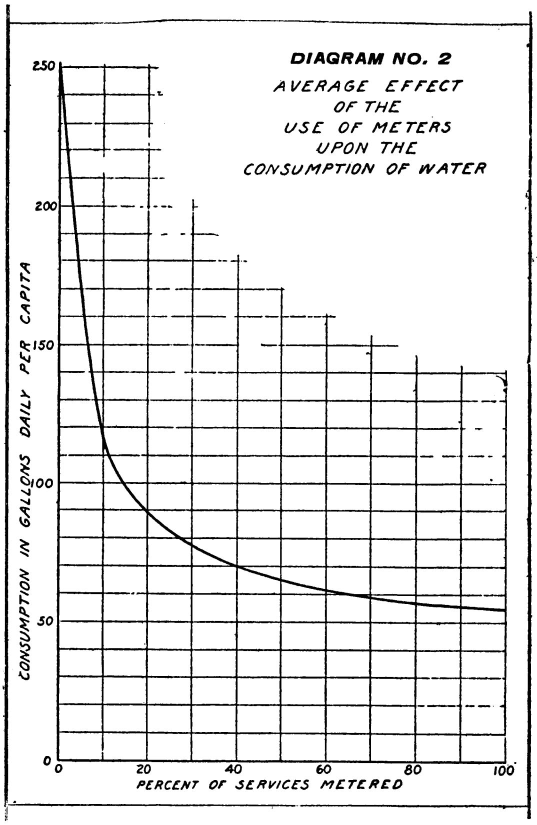
Allowances for the probable quantity of water which will be unaccounted for or wasted in future years may usually be estimated most conveniently as a certain number of gallons per capita or per consumer, the number being based upon present values where ascertainable with due regard for steps which may be taken to reduce existing leakage and waste. The reasonableness of the assumptions thus made should always be checked by calculating what they represent in per cent of total consumption and per mile of pipe.

Effect of Meters in Reducing Waste

The possible reduction of losses due to defective plumbing and to other household waste by the introduction of meters depends upon the care and system with which house-to-house inspections have been made prior to the introduction of meters, as well as upon

the general condition of plumbing which varies greatly in different sections, upon the habits of the people, and in a measure upon climatic conditions.

It is not possible to give a specific statement of the saving which may be effected by meters in a particular community without a deliberate local study. As a general indication of the effect of the



introduction of meters, however, Diagram No. 2, taken from Mr. John R. Freeman's *Report on New York's Water Supply* is presented.

It is dangerous to be too hopeful about the prevention of waste, for, with these hopes unfulfilled and an insufficient distribution system, pressures will be reduced below the point required for satisfactory service.

While the general introduction of domestic meters will usually

result in curtailing household waste, it is inexcusable to place too much reliance upon this expedient while local sentiment is against the domestic meter, and it is poor policy to provide an insufficient distribution system while discussing what ought to be done to educate the public to a greater economy in the use of water.

In providing for the health, comfort, convenience and future prosperity of a community, the engineer must be governed by practical considerations; by what the public will do and not by the theory of what they ought to do; by the efficiency ordinarily attained in municipal departments and not that which should be attained. From the operating and economic viewpoint, waste should be fought and fought hard. Its restriction saves capital outlay for enlarged mains, pumps, filters and reservoirs. It saves operating costs for fuel, coagulants, supplies and labor. A standard of reasonable consumption should be set and its attainment constantly aspired to. From the viewpoint of future requirements, however, sufficient main capacity must be provided so that, under normal conditions, with things and men as we find them, no one shall suffer by reason of his neighbor's waste or the inefficiency of municipal departments. It is well to estimate upon the proper, theoretical, economical per capita consumption as a minimum, and to estimate the future consumption as a reasonably conservative maximum. Nothing will be lost by this, so far as the distribution system is concerned, for the reason that it means only that the mains will have a life of a few years more before replacements or reinforcements are required, and figured on this basis, it matters very little so far as the financial return is concerned whether the pipes as laid are estimated to be large enough for twenty or for twenty-five years.

Effect of Sewers upon Consumption

The presence or absence of sewers will exert a material influence upon the average quantity of water consumed.

Table No. 6 which was obtained from the report of the Committee on Water Consumption previously referred to, gives the average consumption of water in three Massachusetts cities before and after the introduction of a fairly complete system of sewers. As in the case of the introduction of meters, it is not possible to give exact figures representing the probable changes in the use of water

TABLE No. 6

Average consumption of water in three Massachusetts cities before and after the introduction of a fairly complete system of sewers

Gallons per person per day

CITY	YEARS PREVIOUS TO INTRODUCTION OF SEWERS							YEAR WHEN SYSTEM OF SEWERS WAS PRACTICALLY COMPLETED (1891)	YEARS SUBSEQUENT TO INTRODUCTION OF SEWERS									
	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9	19
Marlborough.	13	17	20	21	24	24	25	26	30	30	35	34	37	37	38	38	36	37
Newton.	28	31	33	33	31	36	40	43	50	52	60	65	63	60	57	63	62	63
Waltham.....	37	36	39	33	31	32	33	40	47	53	61	59	71	70	76	88	90	88

which will result from the introduction of sewers in a specific place, but the table illustrates, in a general way, that where a system is being designed for a town without sewers, liberal allowance should be made for the subsequent introduction of sewers.

Variations in Average Per Capita Consumption

The total consumption of water in cities and towns varies between wide limits, as is indicated by Table No. 7 and it is necessary for the engineer in designing a system of distribution to study the local and characteristic uses.

TABLE No. 7

Total consumption of water in various metered and unmetered cities in the eastern United States

CITY	POPULATION	DAILY CONSUMPTION	DAILY CONSUMPTION PER CAPITA
(1)	(2)	(3)	(4)
Connecticut:			
Bridgeport........................	112,144	22,428,800	200
Hartford...........................	126,582	8,640,000	68
Meriden............................	28,228	2,822,800	100
New Haven........................	141,915	21,287,250	150
New London.......................	20,000	3,104,947	155
Stamford..........................	28,106	4,215,900	150
Waterbury.........................	80,289	7,282,213	91

TABLE No. 7—Continued

CITY	POPULATION	DAILY CONSUMPTION	DAILY CONSUMPTION PER CAPITA
(1)	(2)	(3)	(4)
New York:			
Albany	102,344	22,486,000	220
Auburn	36,071	6,542,189	182
Binghamton	51,300	7,242,286	140
Brooklyn	1,786,327	157,500,000	91
Buffalo	446,889	138,100,000	309
Elmira	37,664	4,970,000	132
Ithaca	15,000	2,000,000	133
Kingston	26,354	6,994,821	266
Middletown	15,570		
Newburgh	28,733	4,128,931	144
New York (Manhattan)	2,487,962	303,000,000	104
Oswego	23,747	4,650,064	196
Poughkeepsie	29,203	2,715,879	93
Rochester	235,968	22,180,992	94
Schenectady	86,305	10,615,515	123
Syracuse	146,480	17,577,600	120
Troy	77,382	21,000,000	271
Yonkers	90,156	8,679,915	96
New Jersey:			
Atlantic City	52,098	12,785,000	245
Camden	100,581	12,572,625	125
Elizabeth	80,272	13,164,608	164
Jersey City	287,709	44,882,607	156
Newark	379,211	38,679,522	102
Passaic	63,542	4,575,024	72
Plainfield	22,231	3,440,000	150
Trenton	104,451	20,000,000‡	191±
Pennsylvania:			
Allegheny	140,200	35,134,120	251
Altoona	55,504	5,200,000	94
Bradford	17,000	2,000,000	117
Erie	71,004	11,050,537	153
Johnstown	62,705	10,032,800	160
Lancaster	49,101	5,900,000	120
Norristown	29,697	2,375,760	80
Philadelphia	1,631,956	290,500,000	178
Pittsburgh	385,100	84,991,570	221
Reading	101,628	13,923,036	138
York	48,318	3,160,000	66

Even in places where a large percent of the services are metered, the variation in per capita consumption is very great. This is indicated by Table No. 8. It will be noted that with a single exception, none of the towns listed in this table, has less than 70 per cent of the services metered, yet the gross per capita consumption varies between 38 and 128. The table is presented to accentuate the caution which must be observed in making reasonable allowance for local characteristics in estimating the probable required consumption for a given community.

TABLE No. 8

Variations in total per capita consumption of water in plants having a large percentage of metered services

CITY	PER CENT METERED SERVICES	TOTAL CONSUMPTION GALLONS PER CAPITA
(1)	(2)	(3)
Anniston, Alabama	76	128
Atlanta, Georgia	100	65
Bayonne, New Jersey	100	95
Bessemer, Alabama	70	46
Brockton, Massachusetts	90	38
Cleveland, Ohio	94	100
Consolidated Water Company	85	71
Covington, Kentucky	100	51
Geneva, New York	91	35
Harrisburg, Pennsylvania	83	122
Hartford, Connecticut	98	68
Lexington, Kentucky	98	58
Lincoln, Nebraska	100	40
Milwaukee, Wisconsin	99	105
Montclair, New Jersey	100	66
Newton, New Jersey	86	58
New York Inter Urban Water Company	95	78
Passaic, New Jersey	54	72
Providence, Rhode Island	90	68
Rochester and Lake Ontario Water Company	100	94
Utica, New York	98	59
Yonkers, New York	100	96

An analysis of the distribution of consumption in individual locations will often afford a reasonable explanation for the great variation in per capita consumption. It will be found that the industrial and commercial uses are large in one place, or that the

character of the population in another place is such as to exact a liberal supply of water. In suburban places, large quantities of water are used for lawn sprinkling, more than is generally appreciated.

Progressive Increase in Normal Per Capita Demand

The history of nearly every American city shows that the per capita consumption of water increases as the population increases. In Rochester, New York, where the water department has been conducted along the best lines for years, the per capita consumption increased from 60.2 gallons, in 1879, to 86.6 gallons, in 1907, while during the same period the number of metered services increased from 2 per cent to 70 per cent.

Notwithstanding the efforts which have been made to lessen the quantity of water consumed in Baltimore, the per capita consumption increased from 72 gallons, in 1880, to 120 gallons, in 1909, and this is smaller than in most of the large American cities.

The per capita consumption in the city of Cleveland, in 1874, was 45.36 gallons per day, with 1.28 per cent of the connections in use metered and, in 1908, with 93.61 per cent of the connections metered, the per capita consumption was 100.3 gallons.

These examples may tend to discredit the meter in the minds of laymen. This is not the intention. The City of Cleveland, while illustrating the natural tendency to an increased per capita consumption also illustrates the economy which will result from the introduction of meters. In 1901 the per capita consumption had increased to 169.4 gallons, with 6.42 per cent of service connections metered and the reduction from 169 gallons per capita, represents the saving which resulted from an extended use of meters and proper water waste prevention. Had the per capita consumption continued to increase, as formerly, the present rate would be over 200 gallons per day.

That the presence of meters does exert a marked retarding effect upon the growth of per capita consumption is clearly indicated by the two accompanying diagrams, 3 and 4.

In planning the Boston Metropolitan supply, about fifteen years ago, a very careful investigation was made of the probable requirements of that city, by Mr. Dexter Brackett, now chief engineer, who, at that time, had acquired a large experience in water waste

DIAGRAM NO. 3

FLUCTUATIONS IN THE PER CAPITA USE OF WATER

IN CITIES HAVING LESS THAN 15% OF SERVICES METERED

SMALL FIGURES INDICATE PER CENT OF SERVICES METERED

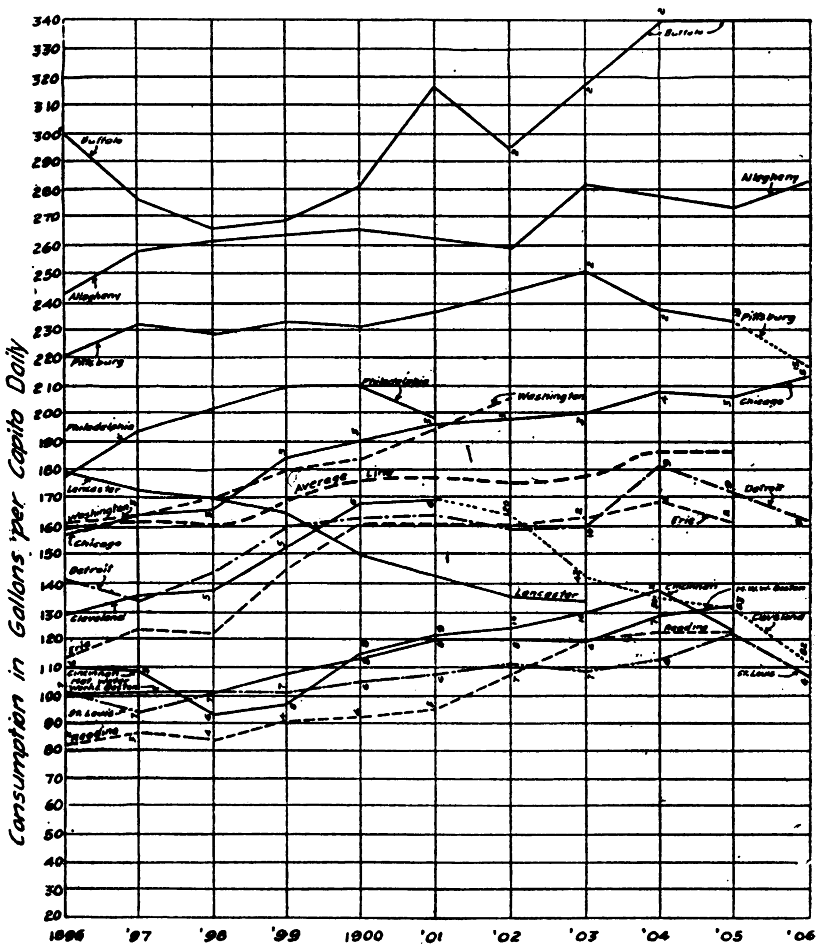
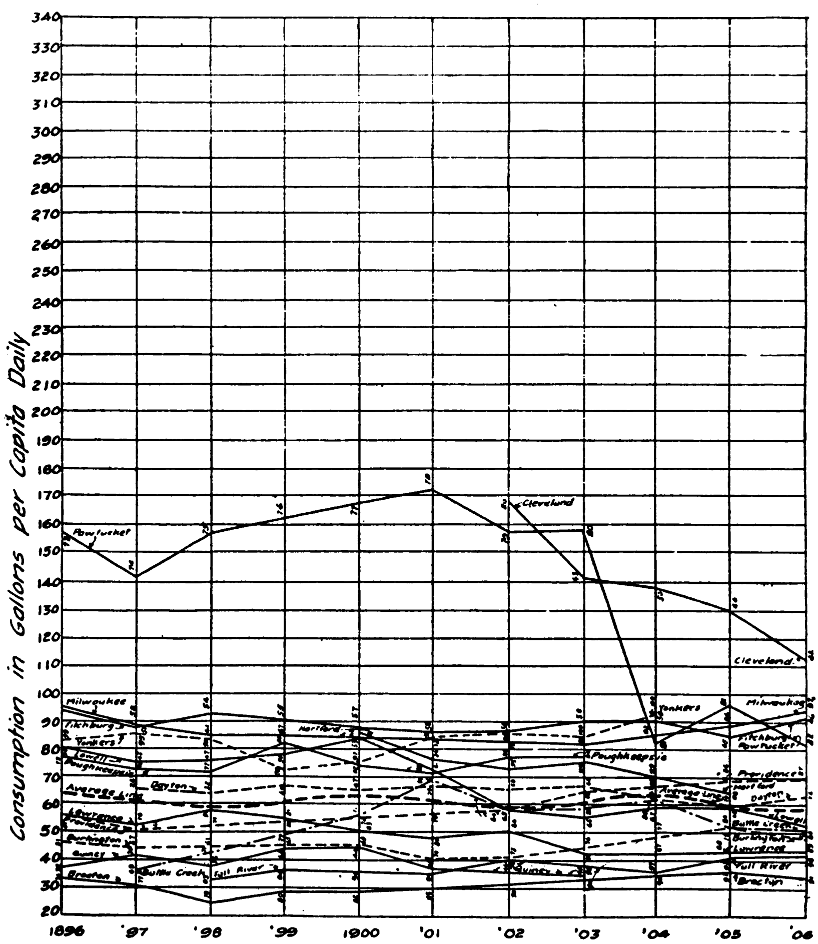


DIAGRAM NO. 4

FLUCTUATIONS IN THE PER CAPITA USE OF WATER

IN CITIES HAVING MORE THAN 50% OF SERVICES METERED

SMALL FIGURES INDICATE PER CENT OF SERVICES METERED



prevention. He estimated the suitable allowance for the Boston Metropolitan District, to be:

	Gallons per Capita
For domestic use	35
For trade and mechanical purposes	35
For public use	5
Waste	25
Total	100

The per capita consumption of water in the Metropolitan District has been as high as 128 gallons per day.

In March, 1906, a careful investigation for the extension and betterment of the Cincinnati Water Works was made by three eminent engineers. After carefully considering the conditions in Cincinnati and other representative cities and assuming that an earnest effort to prevent unnecessary waste would be made at Cincinnati, estimates of the future requirements were based on an average consumption of 130 gallons per capita per day.

The Commission on Additional Water Supply for the City of New York, after reviewing the results of water waste investigations conducted by the writer, decided that the greatest possible saving to be effected by reducing the waste and by decreasing the extravagant use of water, would not provide for more than a few years to come, and based its estimates of the future requirements, which additional works would be called upon to provide, on 150 gallons per day for each member of the population.

In a recent estimate of the probable future requirements of water in Baltimore, made preparatory to plans for a new and additional supply, the engineers decided that it was not prudent to plan new works on the assumption of a smaller per capita use than 130 gallons per capita in 1915; 135 gallons per capita in 1920; 145 gallons per capita in 1930; 150 gallons per capita in 1940.

In estimating probable future demands for water it is advisable where possible to ascertain accurately the amount of water which has been used in the past in the community under consideration, to subdivide the uses of this water as far as possible and, if practicable, to fix upon the probable amount of waste. Then, having determined the total waste, an estimate of waste which would be remediable with the exercise of ordinary care and supervision may be made and the proper correction applied. It is also advisable to check

the local consumption of water with the consumption of towns of like population, location, environment and other characteristics, to see whether the total consumption in the community considered indicates abnormality.

Fluctuations in Consumption

The preceding values for per capita consumption are all averages for the year, and may be exceeded for periods of considerable length.

At the outset of a discussion of the fluctuations in consumption which are noticeable in all water works systems, and must be properly provided for, attention should be called to the fact that differentiation must be made between the fluctuations which occur in a metered and in an unmetered system. The presence of meters introduces a marked levelling effect upon the fluctuations which occur from various causes and, therefore, their presence has a decided effect on the reduction of the peak loads which must be met by a distribution system in an unmetered city. The saving in fixed investment in distribution system due to this levelling effect is not generally appreciated, but must be borne in mind if the best economy is to be obtained in the design.

It is exceedingly difficult to apply the fluctuations which occur in one community to another community, and as portable instruments, such as the pitometer, which are inexpensive and easy to use, are available, actual measurements of the fluctuations to be met in a given place should be made prior to the re-design of a distribution system, where the data available are not sufficient for the purposes at hand.

The daily consumption will frequently be considerably higher than the average during cold winter months due to the opening of bibb cocks to prevent freezing in the mains and service connections. It will frequently be higher than the average in the summer due to lawn and street sprinkling and to the more liberal use of water for bathing purposes. It will be affected, though in a smaller degree, by less marked fluctuations in the temperature of the air, and the amount of rainfall during the summer will produce its effect.

The daily consumption in some communities will be much higher on Mondays and Tuesdays when domestic washing is being done than on Saturdays and Sundays.

The consumption will be much higher during the day than at

night, and will ordinarily, for obvious reasons be much higher for a few hours in the morning and late afternoon than during other hours in the day. These variations will be less marked in large communities than in small ones.

As an illustration of the fluctuations which may occur, Diagrams Nos. 5 to 11 are presented herewith which indicate the existence and extent of these variations in the places to which they apply. The figures presented by the diagrams show the fluctuations in total consumption including that used for commercial, industrial, railroad and other purposes.

Diagram No. 5 gives the variations in the average daily consumption by months in a city of 250,000 people during the year 1907 and the first four months of 1908. It will be noted that the consumption is highest in February in each year, the daily consumption in February, 1907, being 1.08 times the average daily consumption for the year.

Diagram No. 6 gives the variations in the average daily consumption by months from July, 1908, to December, 1912, inclusive in a community in which the population increased from 20,645 to 31,410 during the period covered by the record. In this community, whose average population during the period was approximately 25,000 people, the consumption is highest in July of each year, the daily consumption during July being from 1.12 to 1.20 times the average daily consumption for the year. On this diagram is also noted the consumption during the absolute maximum day of each year. In all but one instance, this maximum day occurs during the maximum one month, and varies from 1.5 to 1.95 times the average daily consumption for the year.

Diagram No. 7 shows the hourly fluctuations in consumption as measured by pitometer in a community of 5,000 people. The record, covering several days, also illustrates well the variations in the daily consumption on different days of the week. It shows an hourly rate of consumption varying from 0.35 to 1.86 times the average rate during the day on which the maximum hour as shown occurred.

Diagrams Nos. 8 to 11, inclusive, show the annual, monthly, daily, and hourly variations in consumption at Auburn, New York, which has about 9 per cent of the service taps metered.

Diagram No. 8 shows the monthly variations in the total average daily consumption from 1892 to 1912 inclusive, also the progressive

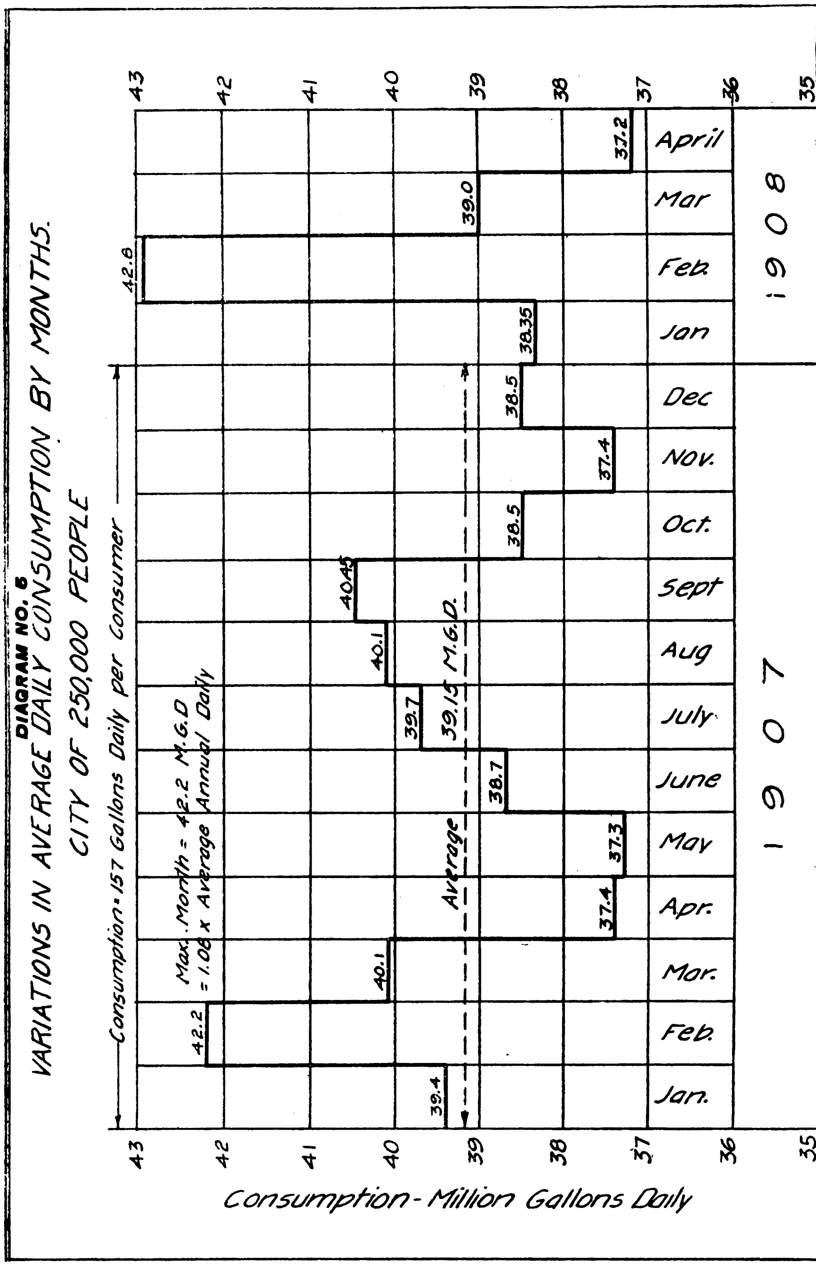


DIAGRAM NO. 6
VARIATIONS IN AVERAGE DAILY CONSUMPTION BY MONTHS.
CITY OF 250,000 PEOPLE
Consumption = 157 Gallons Daily per Consumer
Max. Month = 42.2 M.G.D
= 1.08 x Average Annual Daily
Average 39.15 M.G.D.
1907
Jan. Feb. Mar. Apr. May June July Aug Sept Oct. Nov. Dec
39.4 42.2 40.1 37.4 37.3 38.7 39.7 40.1 40.45 38.5 37.4 38.5
1908
Jan Feb. Mar April
38.35 42.8 39.0 37.2
43 42 41 40 39 38 37 36 35
Consumption - Million Gallons Daily

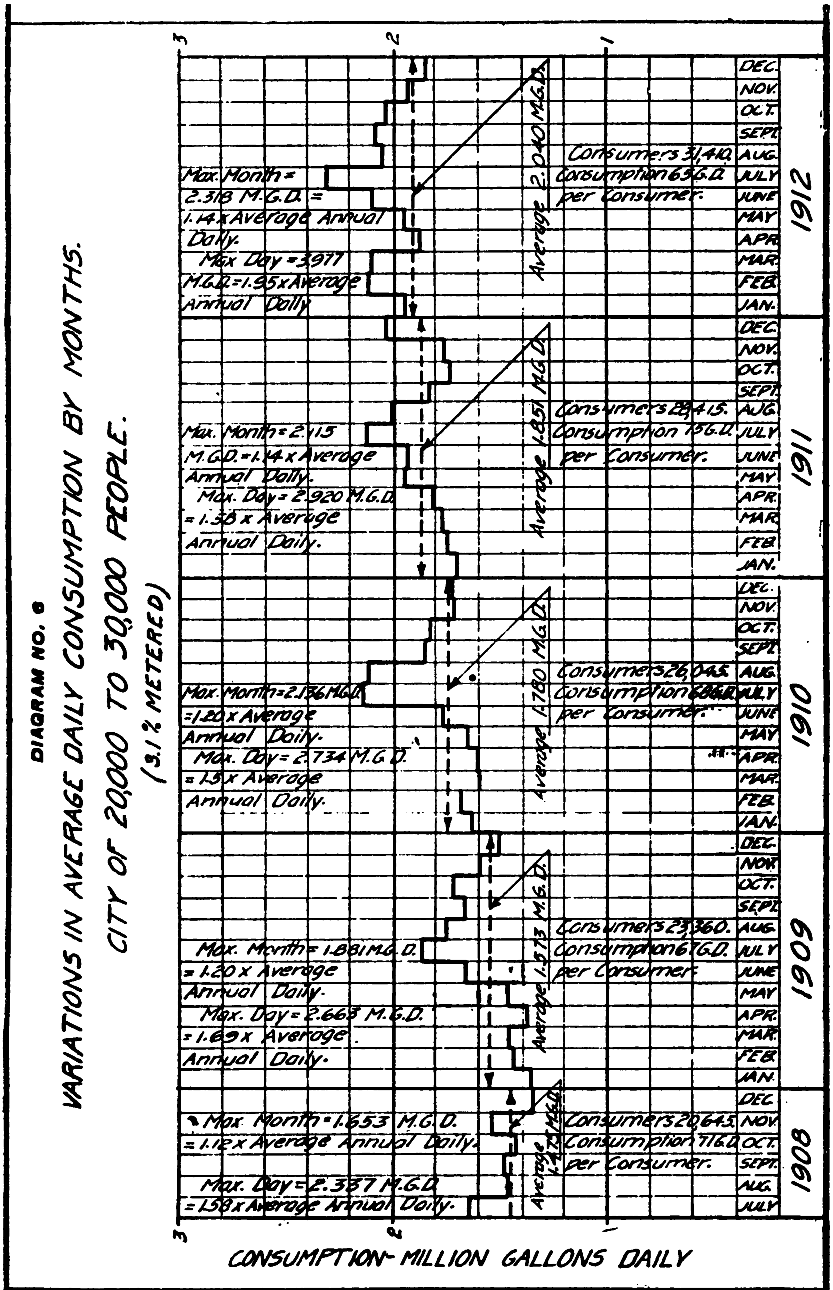


DIAGRAM NO. 6
VARIATIONS IN AVERAGE DAILY CONSUMPTION BY MONTHS.
CITY OF 20,000 TO 30,000 PEOPLE.
(9.1% METERED)
CONSUMPTION-MILLION GALLONS DAILY
1908
Max. Month = 1.653 M.G.D. = 1.12 x Average Annual Daily.
Max. Day = 2.337 M.G.D. = 1.58 x Average Annual Daily.
Consumers 20,645. Consumption 71 G.D. per Consumer.
1909
Max. Month = 1.881 M.G.D. = 1.20 x Average Annual Daily.
Max. Day = 2.663 M.G.D. = 1.69 x Average Annual Daily.
Average 1.573 M.G.D.
Consumers 23,360. Consumption 67 G.D. per Consumer.
1910
Max. Month = 2.136 M.G.D. = 1.20 x Average Annual Daily.
Max. Day = 2.734 M.G.D. = 1.5 x Average Annual Daily.
Average 1.780 M.G.D.
Consumers 26,045. per Consumer.
1911
Max. Month = 2.115 M.G.D. = 1.14 x Average Annual Daily.
Max. Day = 2.920 M.G.D. = 1.58 x Average Annual Daily.
Average 1.851 M.G.D.
Consumers 28,415. Consumption 75 G.D. per Consumer.
1912
Max. Month = 2.318 M.G.D. = 1.14 x Average Annual Daily.
Max Day = 3.977 M.G.D. = 1.95 x Average Annual Daily
Average 2.040 M.G.D.
Consumers 31,410. Consumption 65 G.D. per Consumer.

DIAGRAM NO. 7

VARIATIONS IN DAILY CONSUMPTION BY HOURS
COMMUNITY OF 5000 PEOPLE (UNMETERED)

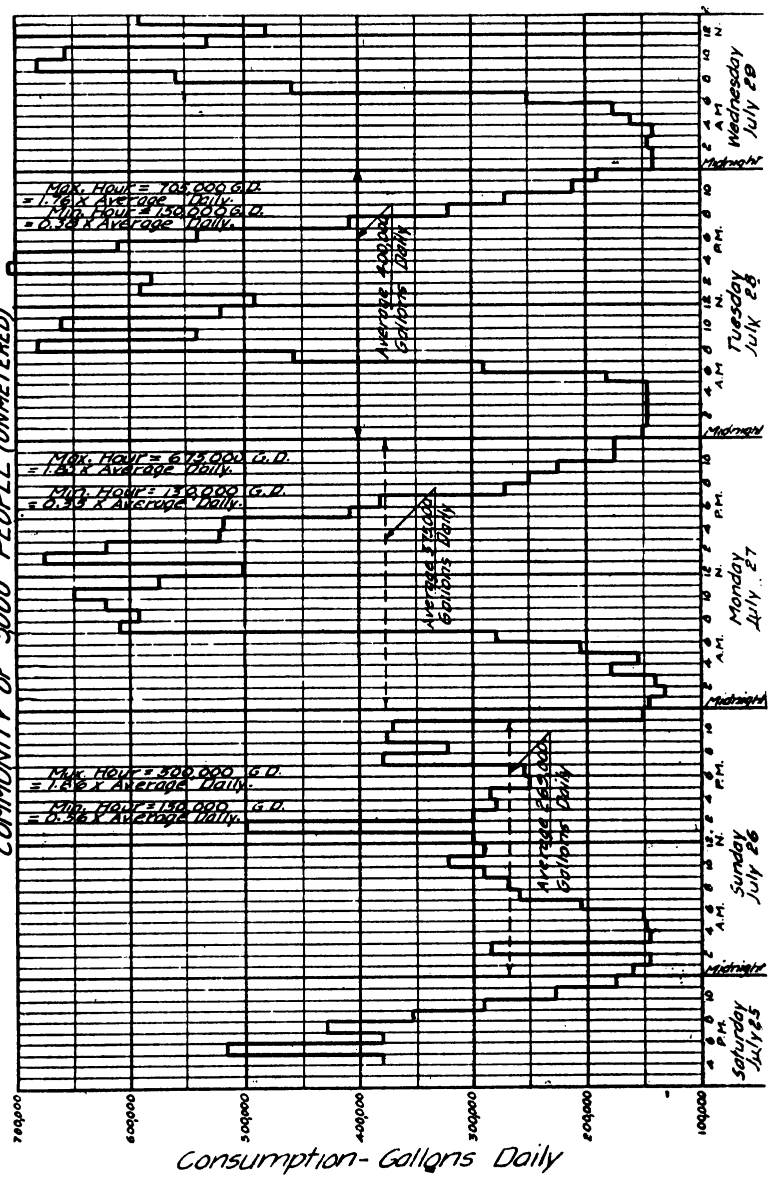


DIAGRAM NO. 8
AVERAGE MONTHLY CONSUMPTION
CITY OF AUBURN, N. Y.
1892 POPULATION = 25,000
1912 POPULATION = 36,000

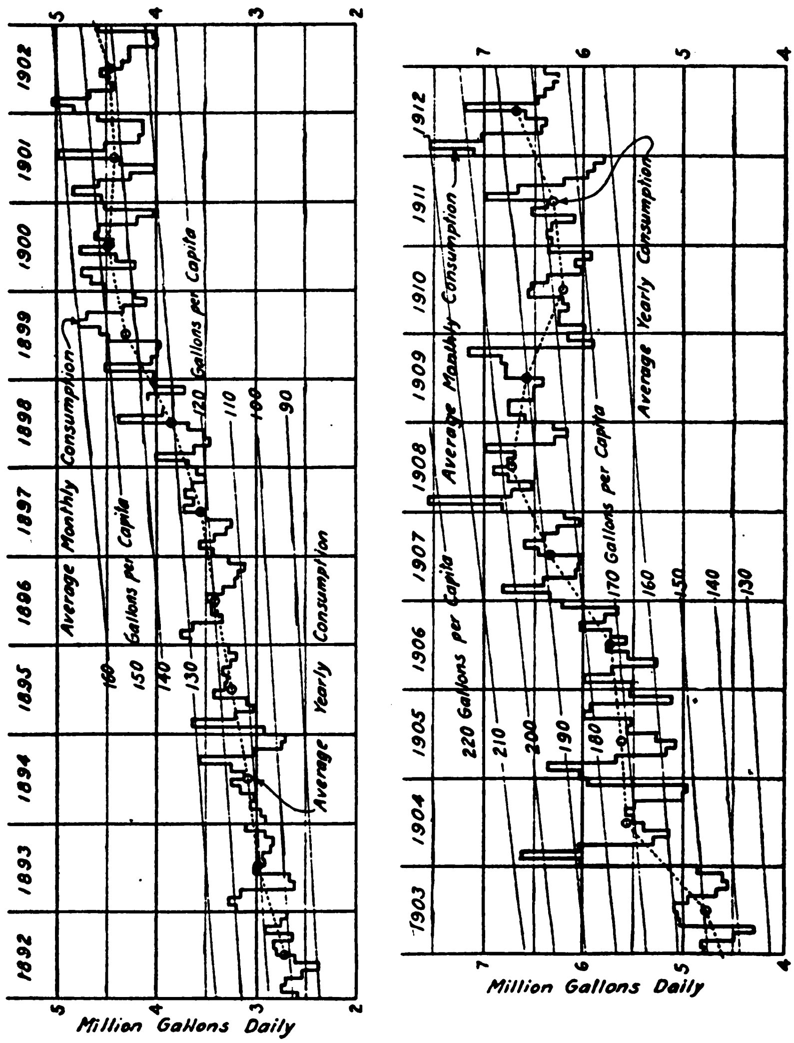


DIAGRAM NO. 9

AVERAGE DAILY CONSUMPTION OF WATER
RAINFALL AND TEMPERATURE OF AIR
CITY OF AUBURN, N. Y.
1912 – POPULATION = 36,000

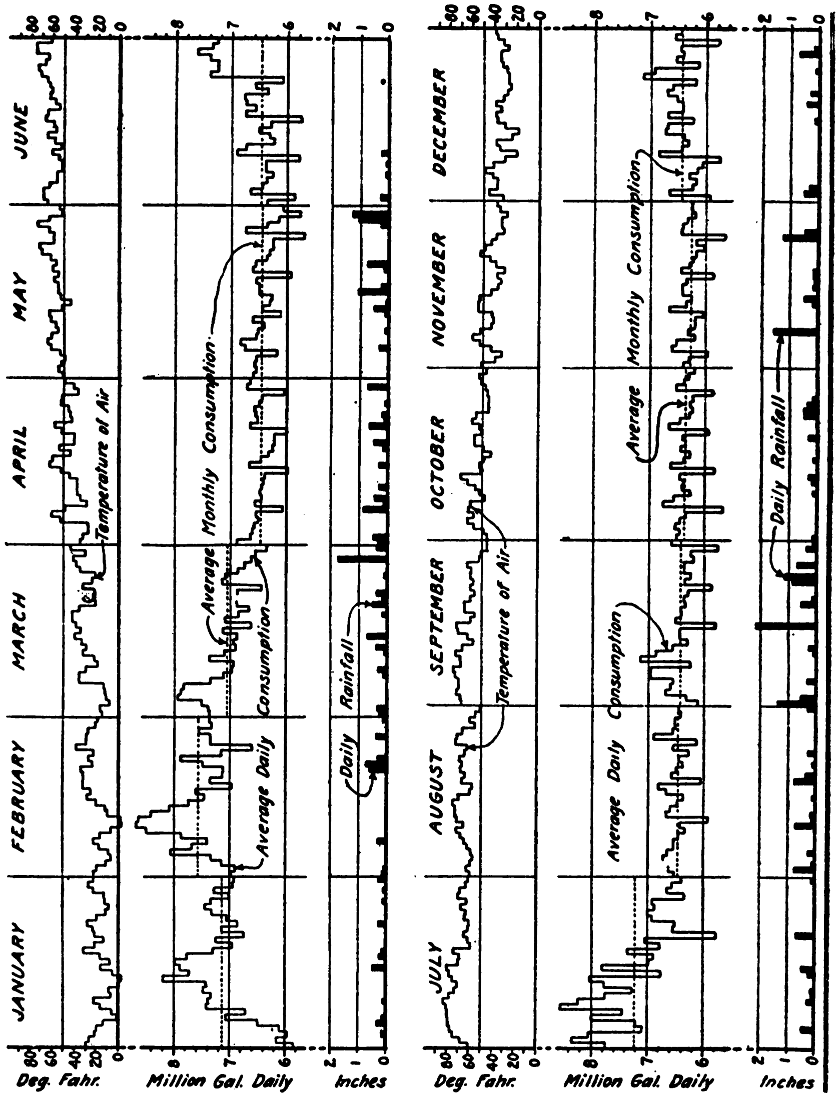


DIAGRAM NO. 10

HOURLY VARIATION IN COLD WEATHER CONSUMPTION

CITY OF AUBURN, N.Y.

1912 POPULATION 36,000.

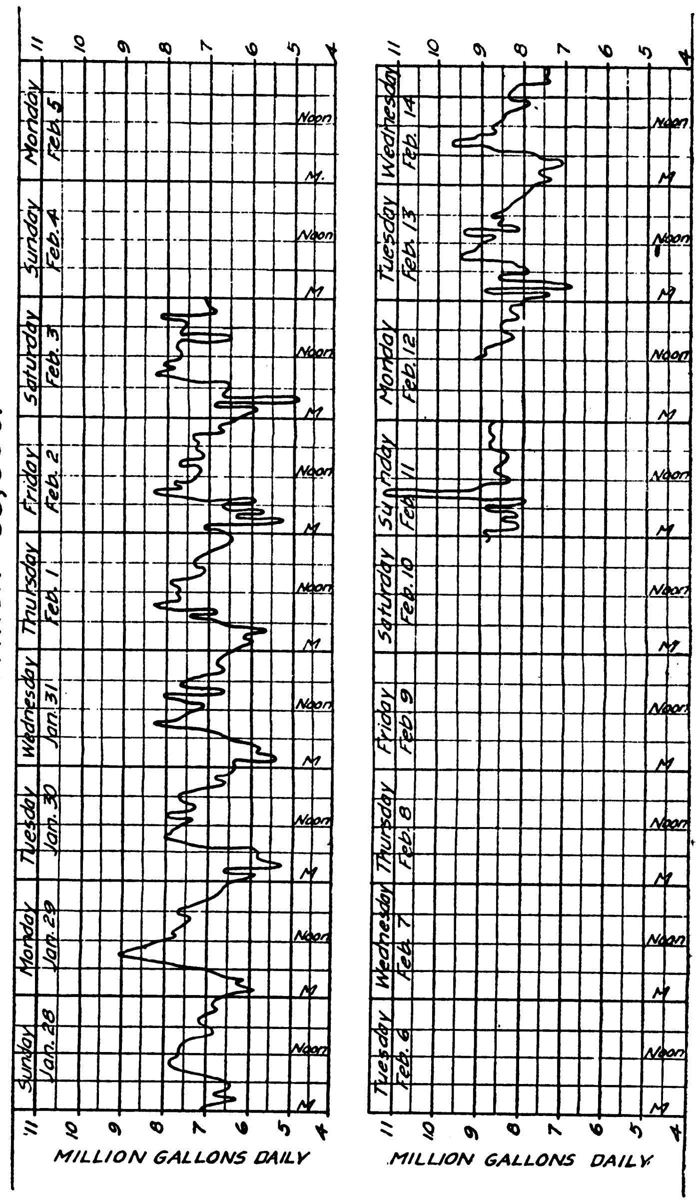
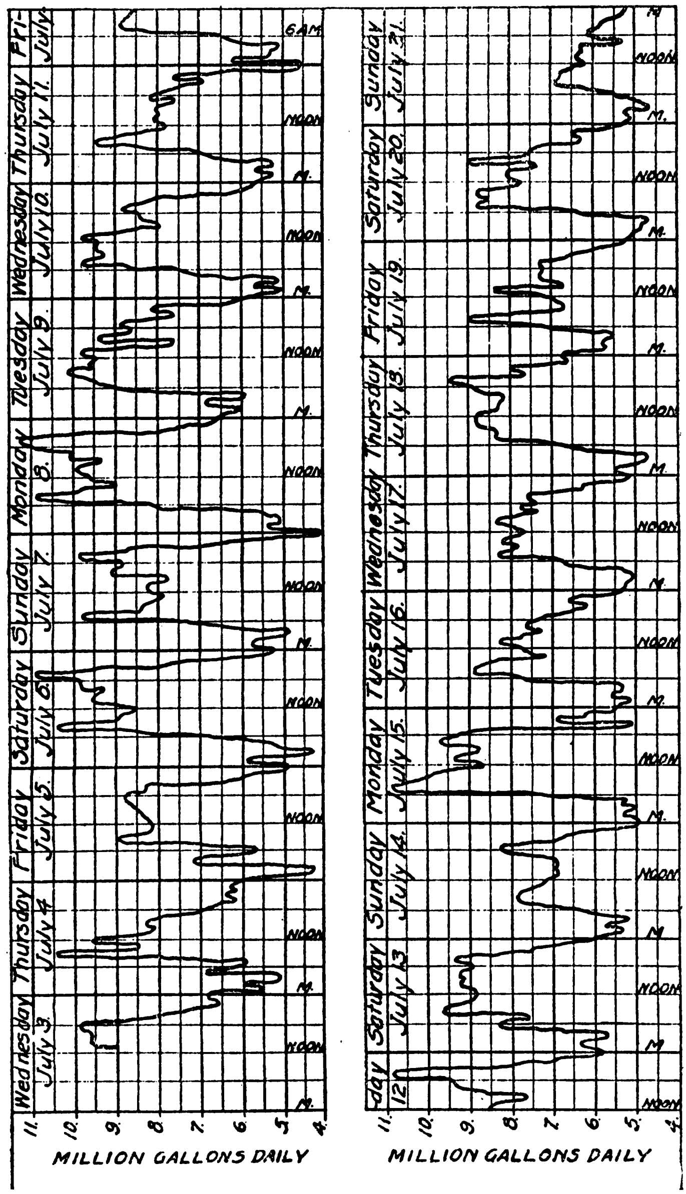


DIAGRAM NO. 11

HOURLY VARIATION IN WARM WEATHER CONSUMPTION

CITY OF AUBURN, N.Y.

1912 POPULATION 36,000.



increase in total and per capita consumption during the period covered by the record. The population during this interval increased from about 25,000 to approximately 36,000 people.

Diagram No. 9 gives the daily fluctuations in consumption for each month of the year 1912, together with the corresponding average daily rainfall and air temperature.

Diagram No. 10 indicates the hourly variations in cold weather consumption from Sunday, January 28, to Saturday, February 3, 1912, inclusive, and from Sunday, February 11 to Wednesday, February 14, 1912, inclusive.

Diagram No. 11 shows the hourly variations in hot weather consumption from Wednesday, July 3, to Sunday, July 21, 1912, inclusive.

These data, all relating to the same community, are interesting and illuminating.

In the twenty-one years covered by the record, the total average daily consumption per capita increased from 100 gallons in 1892 to practically 200 gallons in 1908. The value in 1912 was 188 gallons daily per capita.

A clear relationship is observable on Diagram No. 9 between the average daily consumption and temperatures which are much above or much below the normal. It is also possible to trace in a general way a relationship between the curve of average daily consumption and the daily rainfall as recorded on the same sheet. In July, August, September, for example, there are numerous days on which a heavy precipitation was accompanied or immediately followed by a large drop in the daily consumption.

February was the month of highest consumption in nine out of twenty-one years, July being the highest month during six of the remaining twelve years. The average daily consumption during the highest one month varied from 1.02 to 1.18 times the average daily consumption for the corresponding year. It averaged 1.11 times the latter value. In the year 1912 the day of maximum consumption occurred on February 10, the month of maximum consumption, and amounted to 1.31 times the average daily for the year. On July 8 of the same year the average daily consumption amounted to 1.28 times the average daily for the year.

The hour of greatest hot weather consumption in 1912 occurred about 7 p.m. of July 8, the day of highest hot weather consumption. It amounted to 1.68 times the average annual daily rate.

The hour of greatest recorded cold weather consumption occurred at about 9 a.m., February 11, the morning following the day of highest cold weather consumption. It then amounted to 1.69 times the average annual daily rate, practically the same as the maximum hourly hot weather consumption. In general, higher hourly maxima and lower hourly minima were recorded during the month of July than during the month of February.

For purposes of distribution system design it will not usually be necessary to provide carrying capacity for a quantity greater than the estimated average daily demand during the maximum one week of the period considered, in addition to the fire service requirements. The worst that can happen as a result of failure to design the mains for the occurrence of the maximum fire service requirements coincident with the maximum daily or hourly demand for water for all other purposes, will be a slight reduction in the fire pressures below those which the system is designed to give. Any well designed distribution system is sufficiently flexible to carry overloads for short periods with no other effect than a slight reduction in the maximum fire service pressure.

At all ordinary times, and even during times of moderate sized fires, mains which have been designed to carry the quantities required to satisfy the maximum demands during a conflagration in the maximum week of the maximum year will have ample capacity to deliver the maximum daily and hourly demands without appreciable loss of pressure.

It may also be remarked in this connection that there is a normal tendency to a reduction in the volume of water required for purposes other than fire during the occurrence of an exceptionally large fire, and, finally, it may be said, that the probability of a conflagration occurring coincidentally with the maximum daily or hourly flow in a maximum year is so remote that it would not be commercially expedient to provide for it.

Abnormal Fluctuations in Consumption

In addition to the normal hourly, daily and seasonal fluctuations in the quantity of water required, every water works plant is subject to more or less sudden, violent and abnormal fluctuations in demand. This is particularly true of small installations, though these sudden demands must not be lost sight of even with larger

plants, as they materially affect the size of mains required to give adequate service under all conditions.

Although many kinds of industrial service entail sudden demands for large quantities of water which must be given special study in order that they may be met without crippling the service, the chief cause of these sudden and violent fluctuations is the fire service requirement.

In a plant supplying on the average 1,000,000 gallons per day, which is equivalent to approximately 700 gallons per minute, it may be necessary to supply on short notice eight or ten fire streams delivering 250 gallons per minute each, a total of from 2,000 to 2,500 gallons per minute, or from three to four times the normal delivery. This delivery must be met without undue loss of pressure if the fire service is to be effective, and it is necessary in designing a distribution system to make provision for these sudden and excessive demands.

Fire Service Requirements

A number of rules and formulae have been deduced for estimating the quantity of water necessary to afford proper fire protection in communities of different size. No one of these formulae is of universal application, and, for the most part, they give results considerably in excess of the values which actually obtain generally in the United States.

Table No. 9 gives a few of these formulae.

The National Board of Fire Underwriters does not estimate the number of fire streams required in the congested value districts in cities of different size by formulae, but has determined the number which it considers adequate in a large number of American cities from a special investigation of the conditions in each place. The formula given as that of the underwriters is the equation of a curve representing the average of the published requirements for the cities investigated and reported upon by this Board from 1905 to 1911, classified according to size. See paper "Reasonable Return for Fire Hydrant Service" by Metcalf, Kuichling and Hawley, *Proceedings of the American Water Works Association*, 1911.

That there is no fixed relation between population and the maximum number of fire streams required for adequate fire protection is indicated by a study of the individual points from which this equation was deduced. There is, for example, one instance in which

the Board estimates that 10,000 gallons per minute, equal to forty simultaneous fire streams of 250 gallons per minute each, under a flowing pressure of 75 pounds at the hydrant, is necessary for the proper protection of a city of 52,000 people and another instance in which this amount is deemed adequate for a city of 360,000 people.

TABLE NO. 9

Quantity of water, and number of fire streams required for fire service by various formulae

	John R. Freeman (1892)		Allen Hazen Emil Kuichling (1897)	National Board of Fire Underwriters (1910)
	Maximum	Minimum		
(1)	(2)	(3)	(4)	(5)
Formula giving total quantity of water in gallons per minute required for fire protection service in American towns and cities, at 250 gallons per fire stream per minute	$Q = 250Y$	$Q = 25Y$	$Q = 250Y$	$Q = 1020\sqrt{X} \times (1 - 0.01\sqrt{X})$
Formula giving total number of fire streams of 250 gallons per minute each, required for fire protection service in American towns and cities	$Y = \frac{X}{5} + 10$	$Y = 1.7\sqrt{X} + 0.03X$	$Y = 2.8\sqrt{X}$	$Y = \frac{Q}{250}$

X = Number of thousands of inhabitants.
Y = Total number of fire streams required.
Q = Total quantity of water required, gallons per minute.

The wealth per capita, character and location of hazards, and other individual characteristics unrelated to the population of a city, are material factors in the determination of what constitutes satisfactory fire protection. Formulae should, therefore, be used with great caution, in the determination of the number of fire streams required, and individual judgment founded upon local inspection should control.

Subdivision of Water Consumption by Districts

The present and future domestic and public consumption of water in each ward may be assumed to be proportional to the present and estimated future ward population. In some instances, the

accuracy of this assumption may be modified by the fact that certain wards may be supplied in part from local sources, or that most of the non-consumers are located in one or a few wards. Also, difference in the character of the population may increase or diminish the per capita consumption in different wards, but with a knowledge of local conditions and with the exercise of proper judgment, the estimates of the ward consumption may be modified accordingly, if such modifications are deemed necessary.

In considering methods for the proper subdivision of the demands in local areas, it must be borne in mind always that there are so many variables in the supply and distribution of water that it is not possible to figure exact quantities. As is the case in the design of sewers, the distribution system must have a certain factor of safety. Also, owing to the flexibility of a distribution system, particularly where it is reinforced by a great number of smaller pipes forming what might be termed a subsidiary distribution system, deviations in the center of supply from those assumed have but small effect on the usefulness of the system. Moreover, the only effect of a more rapid increase in a certain locality than was anticipated will be a slightly reduced pressure or a shortening of the useful life of the system as planned with the concomitant necessity for reinforcements.

PRESSURES

Service Pressures Required

Following the determination of the immediate and probable future demands for water comes the question of the pressure under which this water should be delivered. If there were no draft of water from the mains, the pressure throughout the system would be that ordinarily termed "static pressure," or the pressure resulting from the elevation of the water in a reservoir. A draft of water from the mains, however, immediately sets in motion the mass of water therein contained, causing friction which is proportional to the draft, and which must be overcome. The dynamic or service pressures at various points on the system may be greater or less than the corresponding static pressure. When the supply is from a reservoir, the service pressure at any point on the distribution system will be less than the corresponding static pressure by the amount of the friction loss between the reservoir and the point considered. When water in excess of the immediate requirements is flowing from a

pumping station into a storage or distributing reservoir, the dynamic pressure at all points between the pumping station and the reservoir will be greater than the corresponding static pressure from the reservoir.

When fire service is furnished directly from the mains, service pressures of not less than 70 to 75 pounds at the hydrant under conditions of maximum draft should be maintained in the congested

TABLE NO. 10

Discharge of 1⅛-inch smooth hose nozzles Hydrant pressure required—Height and distance of jet

		Indicated pressure by gauge attached at base of play pipe and set level with end of nozzle	Extreme height of jet: Average of highest drops, vertical jet, still air	Extreme height of jet: Maximum limit of height as good effective fire stream with moderate wind	Extreme horizontal distance reached by jet: Average extreme drops at level of nozzle with still air	Extreme horizontal distance reached by jet: Maximum limit of distance as good effective fire stream with moderate wind	Gallons per minute discharged	Pounds pressure required at hydrant (or steamer) while stream is flowing to maintain pressure at base of play pipe, as per first column, trough various lengths of 2½ inch ordinary best quality rubber lined hose—inside smooth: 50 ft. length	100 ft. length	200 ft. length	300 ft. length	400 ft. length
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		lbs.	*ft.*	*ft.*	*ft.*	*ft.*		*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Feeble streams		5	11		19		84	6	7	9	10	12
		10	22	18	39	22	119	12	14	17	20	24
		15	32	27	59	31	146	19	21	26	31	35
		20	43	36	80	38	168	25	28	34	41	47
Ordinary fire streams	Fair	25	54	44	99	44	188	31	35	43	51	59
		30	64	52	115	50	206	37	42	52	61	71
	Good	35	74	59	130	54	222	43	49	60	71	82
		40	84	65	142	59	238	50	56	69	81	94
		45	94	70	152	63	252	56	63	77	92	106
	Excellent	50	104	75	162	66	266	62	70	86	102	118
		55	113	80	170	69	279	68	77	95	112	130
		60	122	83	178	72	291	74	84	103	122	141
Unusually strong streams		65	130	86	185	75	303	81	91	112	132	153
		70	136	88	191	77	314	87	98	120	143	165
		75	142	90	197	79	325	93	105	129	153	177
		80	146	92	203	81	336	99	112	138	163	188
		85	150	94	209	83	346	106	119	146	173	200
		90	153	96	214	85	356	112	126	155	183	212
		95	156	98	219	87	366	118	133	163	194	224
		100	158	99	224	89	376	124	140	172	204	236

value districts, although 50 to 60 pounds minimum will usually suffice for residential sections. With these pressures, fire streams throwing from 200 to 250 gallons per minute through $1\frac{1}{8}$ inch smooth nozzles attached to 200 feet of $2\frac{1}{2}$-inch ordinary, best quality, rubber lined hose may be obtained, as will be seen from Table No. 10. The data there presented are taken from the monograph *Fire Stream Tables* published by the Associated Factory Mutual Fire Insurance Companies, and based upon experiments conducted by John R. Freeman in 1888.

Even with service pressures of 70 to 75 pounds in the congested value districts, it may be necessary, in order to insure the proper protection of modern buildings of great height, either to equip and maintain one or two fire engines, the number depending upon the character and size of the district, and of the buildings located therein, or to require that the property owners install and maintain underwriters' pumps to boost the fire pressure on the distribution mains. For all ordinary towns and cities, however, 70 to 75 pounds at the hydrant will give adequate fire service without the necessity for the use of portable fire engines.

Where fire engines are used, a service pressure of 30 pounds minimum on the mains will usually be ample in residential sections, as this pressure will insure the delivery of water to the fourth story of an ordinary building. With this minimum service pressure some of the higher buildings, such as hotels and apartment houses, may be obliged to install local pumping plants to raise the water for distribution in the higher stories, but in view of the expense of maintaining high pressures for ordinary distribution it is but just that this cost should be borne by the parties benefiting, rather than by the general public.

Number of Service Pressure Districts

In considering the question of pressures, the designer should weigh thoroughly the relative economy of creating more than one service pressure district in cities where there are large differences in ground elevation. If these differences are marked, it may be necessary to create two or more entirely distinct service pressure districts in order that the required pressure at high elevations may not produce undesirably high pressures in the low lying areas. When this is done, the design of the distribution system in each service district may become a problem complete in itself, as, for example,

in the case where each service district is supplied from a separate source, or the systems may be inter-related and inter-dependent, as in a situation where the feeder mains of one service pressure district must be of sufficient size to carry the water consumed in one or more of the others. Take, for example, the case where water for an entire city is delivered to the highest district, and thence through pressure reducing valves to the pipes in the lower districts. Another case would be when the water is pumped through the supply mains of a low pressure district before being repumped to the high service mains. Even when the differences in ground elevation are not excessive, it may be advisable to create more than one service pressure district in the case of pumped supplies, thus reducing the pressure at the pumps, and, therefore, the cost of pumping.

Static pressure

Having decided upon the service pressures required at various critical points of a system, and the number of service pressure districts into which the city will be divided, the next step is to determine the size of mains required to convey the estimated quantities of water at the required pressures from the immediate source to the various points of use. This source may be a pumping station, distributing reservoir, or the point at which a conduit or supply main delivers to the distribution system.

The problem presented may involve fixed pressures at the immediate source, as, for example, where one has to deal with existing pumping plants, distributing reservoirs, or conduit lines, the elevation of or pressure from which is fixed. Under these circumstances, the sizes of the distributing mains must be figured so that the losses in friction between the immediate source and the points of use shall not exceed the difference in pressures at the two points.

The problem presented may be one in which the initial pressures are not fixed, and where the designer may, at his discretion, determine upon the most economical pressures to be carried at the immediate source. He is then at liberty to adjust pressures and pipe sizes in the distribution system so as to increase or diminish the friction losses therethrough in such ways as economic considerations may suggest.

The problem presented is really the determination of the static pressures required to produce most economically the desired serv-

ice pressures, or the determination of the most practical static pressure to be used. The most advantageous static pressure will be that at which the total annual cost of supplying satisfactory service is a minimum.

Below are listed the principal elements in the construction or operation of a water works plant which will increase or decrease with an increase in pressure carried. The effect of these several elements upon the total annual cost of supplying water must be appraised by the designer and carefully weighed and compared under the various static heads considered, preparatory to a final decision.

Elements in the design or operation which will increase with an increase in static pressure—other things being equal.

1. Cost of pipes composing the distribution system, excluding feeder mains.
2. Weight and strength of house service connections and plumbing fixtures.
3. Cost of service pumping engines.
4. Cost of boilers, stacks, and pumping station auxiliaries.
5. Cost of fuel per million gallons pumped.
6. Cost of repairs to mains in distribution system.
7. Cost of repairs to house service connections and plumbing.
8. Cost of water wasted through leaks in distribution system.
9. Cost of water wasted through house service connections and leaky plumbing fixtures.
10. Quantity of water used per consumer.

Elements in the design or operation which will decrease with increase in static pressure—other things being equal.

11. Cost of pipes composing the feeder mains.
12. Diameter of house service connections.
13. Number and capacity of booster plants required to increase pressures in restricted high areas.

Some of the elements listed above appear at first sight to exert an appreciable influence on the cost of the plant. Analysis, however, will show that a number of them may be discarded from serious consideration.

Generally, the experienced engineer will be able to weigh the relative effect upon the cost of the several considerations affecting the selection of the most advantageous static head, without elaborate calculations of the relative economy of several schemes.

In addition to the effect exerted upon the cost by the elements mentioned above, the cost may be affected by external considerations, characteristic of the particular community considered, such as the greater land values of the reservoir sites at low elevations, or

vice versa, topographical considerations which would make the cost of a reservoir at one elevation more costly than one at some other level, or the existence of expensive structures which it would be commercially inexpedient to discard.

Having now discussed generally the various external features affecting the design of a pipe distribution system, we come to the specific consideration of the system itself.

The function of a pipe distribution system is the conveyance of water from the point at which the water is delivered to a community to the point at which it is to be used. This delivery must be accomplished in such a manner that an uninterrupted and adequate supply of water under satisfactory pressure will be available at every point on the system under all conditions of demand. The supply must be sufficient in respect of pressure and volume not only to meet the present and future demands of ordinary domestic and public consumption, but to supply the needs of large industrial consumers and for the extinguishment of fires. It must be able to meet not only the *average* present and future demands of these several classes of consumers, but such of their maxima as are likely to occur simultaneously. The pipes should be of a size sufficient to supply these maxima after proper allowance has been made for deterioration in the carrying capacity of the mains as a result of tuberculation and from other causes.

The delivery of water must be accomplished at a cost as low as is consistent with a wise provision for the future growth of the community to be served. By low cost is meant not necessarily the first cost, but the total annual cost including fixed charges, depreciation, replacements, maintenance and incidental costs chargeable to poor construction, such as losses of water through leakage, etc.

The actual design of a distribution system including a detailed analysis of the effect of various elements herein discussed upon the cost thereof will be left for another paper.

DISCUSSION

Mr. John W. Alvord: Mr. Hill has gone very carefully into a very important matter when he points out the large investment made in our distribution systems and the usually scant attention given to the design, care and enlargement.

It is a matter of common knowledge to those of us who investigate a great many plants that many of them are deficient in distribution capacity, and that this condition is usually caused by the growth of the community, the large investment involved, and the economies demanded by the different administrations of the city government from year to year. These influences cause the distribution system to pass into inefficiency almost insensibly. Without a thorough and general over-hauling at stated intervals, this often results in a public calamity and unquestionably a great deal of good can be done by having a careful study of distribution systems made and plans outlined for enlargement and growth, once in a given number of years, depending on the growth of the city. The speaker would point out, however, that the proper capacity of a distribution system design rests almost wholly on the fire protection requirements. It must be designed for the fire protection and when so designed is usually ample for all other purposes. This fact simplifies greatly the questions which must be studied with reference to it. There is, however, a great deal of data which can be gathered and studied both with reference to the present and the future needs along the lines of fire protection. It would certainly be very profitable if studies of this kind could be more often made.

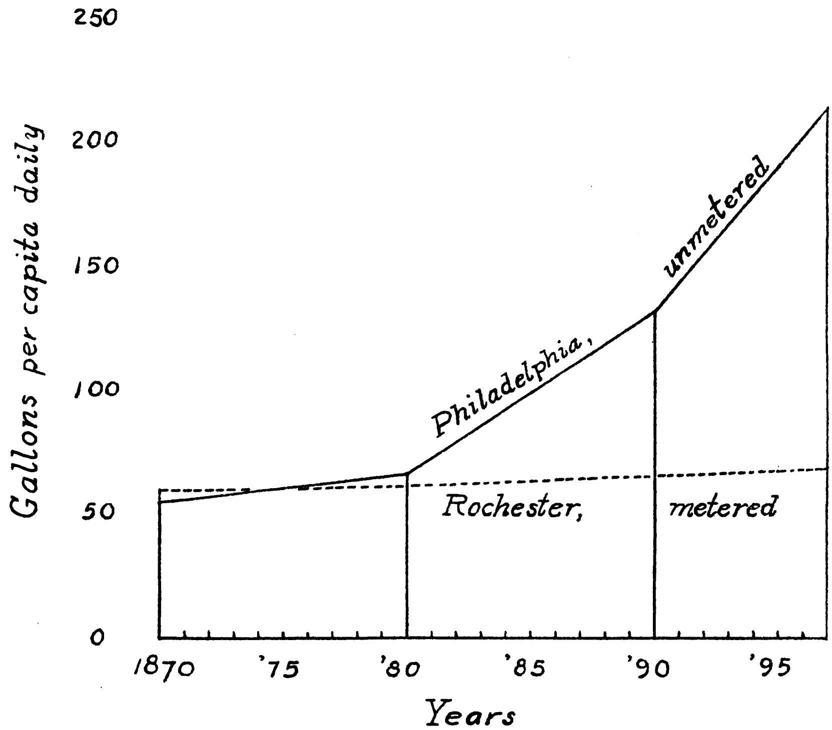
MR. JOHN C. TRAUTWINE, JR.: Mr. Hill has mentioned the case of Rochester, N. Y., where, forty years ago, with less than 2 per cent of the taps metered, the consumption was less than it is today with nearly all the supplies metered; but Mr. Hill, the speaker is sure, would not wish to cite this case as arguing inefficiency of the meter as a waste-restricter.

The object of metering should be to restrict waste, not to discourage legitimate use; and, as the case of Rochester shows, legitimate use properly increases as we advance in civilization and in culture.

Hence, in order to estimate the value of the meter in Rochester, we must compare the present consumption, with nearly all supplies metered, not with the consumption of forty years ago, but with *what the consumption might now be* if meters had not been generally applied.

And, if it be objected that we have no data as to what the Rochester consumption might now be, without meters, the speaker sug-

gests, for comparison, his own unhappy city of Philadelphia. Here, although the city charter leaves such questions to the department of public works, they are really settled, in defiance of the charter, by the ignorant populace and by its representatives in the City Councils; and the water meter is still practically unknown.



INCREASE IN DAILY PER CAPITA WATER CONSUMPTION.
ROCHESTER, N. Y., METERED.
PHILADELPHIA, UNMETERED.

Forty years ago, our (unmetered) consumption was about the same as that of then still unmetered Rochester; but, during the forty years, while Rochester, steadily increasing its use of meters, has kept its consumption down to a figure but little greater than that of forty years ago, Philadelphia's consumption, still practically unmetered, has quadrupled.

The nature of the comparison is indicated by the accompanying sketch, drawn roughly to scale.

Mr. Hill mentioned, incidentally, some of the disadvantages under which small communities labor by reason of their smallness and of their consequent lack of means. For instance, while a large city can well afford to engage the services of a commission composed of the highest-paid engineers of the country, the small town must be content with talent of a lower order, if indeed it does not force its problems of extension, etc., upon its already overworked and underpaid superintendent.

Now this consideration, which affects all the relations of the small town, often compelling it to false economies in all directions, emboldens the speaker to venture the prediction that, fifty years from now, all the municipal water supplies of the country will be administered from Washington, or from wherever the national capital may then be, and that, a hundred years from now, all the water supplies of the world will be administered from the world capital. If this sounds chimerical, the speaker asks you to remember that our always progressive Massachusetts friends have already made a notable move in this very direction, in the creation of their Metropolitan Water and Sewerage Board, which administers the supply not only of Boston City, but that of adjacent communities, which, formerly, had their separate supplies.

In Italy also, the national government is constructing a gigantic supply, carrying spring water through the Apennines, at a total cost of some $30,000,000, for the supply of the arid district of Puglia, on the opposite side of Italy, with its population of about 3,000,000.[1]

The usual answer to predictions of centralization is that each community knows its own needs and resources better than could a national bureau at Washington; but this is disproven by the two cases just mentioned, and by the fact above cited that the smaller community cannot afford to employ the highest talent; whereas the predicted centralization will give to every community, large or small, the benefit of a large organization of experts, with resident assistants in each community, and with facilities for gathering and using information as superior to those of the present consulting engineer, as those of the United States Weather Bureau are superior to those of any possible private organization of weather experts.

[1] Since writing as above, the writer has received, from the American Society of Civil Engineers, a circular from its special committee "on a National Water Law."

And, even if each community best knew its own problems, it need scarcely be mentioned that it has not the nation's power of physically solving those problems; and it must be borne in mind that, in the next fifty years, we, or our successors, will have attained to a far livelier realization than at present of the fact that the health and wealth of the whole are dependent upon those of each part.

And this consideration leads to the controlling one that, even if each community had the necessary understanding of its own needs, and the means for satisfying those needs, it would be glaringly absurd to suppose that it has the knowledge and power and disposition to adjust the supply of those needs to the needs of its neighbors.

Under the predicted centralization, the present squabbles between neighboring towns, over sources of supply, and the spectacle of a great city supplying its own needs with practical disregard of the needs of other communities within reach of its supply line, will be looked back upon with sorrowing wonder that so imperfect a civilization could so recently have existed.

Mr. Nicholas S. Hill, Jr.: The author would like to say to Mr. Trautwine that the illustration of the increase in per capita consumption notwithstanding the introduction of meters, was not made for the purpose of showing that meters were not productive of economy; but rather to prevent the water works man, in designing his distribution system, from saying that because of the introduction of meters there would be no further increase. If Mr. Trautwine closely followed the paper he would remember that the author said, particularly in the case of Cleveland, that if meters had not been installed the per capita consumption today would have been probably 100 gallons in excess of what it is at the present time; showing that although there was a gradual and continued tendency toward an increase, notwithstanding the introduction of meters, yet the saving due to the introduction of meters was enormous.

The author also wants to say that he thinks that this matter of having insufficient mains to provide for proper expansion of the system from time to time, as the requirements may demand, is one of the wrong financial policies upon which our water works systems are carried forward. If it can be shown that by laying a 10 inch pipe in lieu of a 6 inch today, the gross cost of that plant twenty years hence would be less than by laying the 6 inch main today and laying another 6 inch main ten years hence, it is only fair to

assume that the policy of laying a 10 inch main today is going ultimately to redound to the better financial interests of the plant.

The point that the author wants to make is this, not to let the first cost override all other considerations; a tendency to which the American people are or have been strongly inclined; an inclination which is characteristic of every new nation and every new community, because of financial stress and the difficulty of raising the funds for the first outlay. But we are fast getting into such a financial position that we are enabled to sit down, sharpen our pencils, and consider not first cost alone, which is only one element of the cost. If we could only fully realize that the first cost is only one element of the cost, we could sharpen our pencils and determine what is going to be the lowest average cost, not the first cost only, but also depreciation, interest, maintenance, and replacement, in fact, all the elements that go to make up the total cost and should be included therein.

Mr. Paul Hansen: May the speaker ask Mr. Hill what method he would employ in the designing of an ordinary cast iron distribution system; that is, how many years in the future he would think it necessary to provide for and how he would go to work to forecast the future proper demands within the period taken?

Mr. Nicholas S. Hill, Jr.: The author tried to take up that question in the paper which he presented to the Association, by showing the relative cost at the end of a period of twenty years, of laying a small main now, and duplicating it at the end of ten years, compared with the cost of laying a larger main now. This is the simplest way that he knows of getting at it. In general, his experience has led him to believe that it is economical to plan at least twenty years ahead; that a water works department or water works company will be in pocket at the end of twenty years, if today they plan for that period rather than to plan simply to take care of immediate needs as they see them today.

Mr. J. N. Chester: Most of us have visited Washington and probably been taken by professional guides out to that side of the capitol which does not face the city and have been told by the guide how when George Washington and his architect laid out the city they intended that it should be built to the east of the capitol building,

but the real estate dealers and others decreed to the contrary, and it grew in an absolutely opposite direction from what Washington intended, when he laid out the city.

Now while Mr. Hill's paper presents a compilation of a great deal of data, especially as to monthly, daily and hourly consumption, which is valuable for reference, his conclusions in the latter part of the paper, and the theories laid down, it would seem are applicable more to new towns and cities and to new conditions than they are to the conditions that we must meet. The cases in which engineers east of the Mississippi River are now called upon to design entirely new distribution systems are very infrequent; in fact, do not occur in a lifetime with some of us; but the problems against which we are constantly bumping our heads are those of the cities now in existence, and they are being drawn hither and thither by not only the real estate agent but by the location of new factories, public institutions, railroad shops, etc.; all of which create abnormal conditions, and it is not a matter of what can you do theoretically, but what can we do to make the best use of what we have and add to the present installation sufficient to meet the demands that are being created. Butler, Pa., nestled down among the hills, thirteen years ago had an average consumption of not quite 2,000,000 gallons per day. The Standard Car Wheel Company located its plant at that place, and doubled the population of the town in three years. It was not a matter of theory, it was not a matter of taking up old pipes, but we reinforced the old system and also got mains into that part of the town where the growth had been created for this enormous new industry.

It is not a new thing, especially in the district that we have operated in, which is east of the Rocky Mountains, to find cities being drawn on in just that way; the speaker cannot see just how we can apply these formulas of cost and still best meet local conditions. We must meet the conditions that we have.

Another thing to which exception may be taken in Mr. Hill's paper, is the statement that fires seldom occur at times of maximum consumption. The speaker has been responsible for the operation of a number of water works, and can say that fires do often occur at times of maximum draft, and when they do they are very embarrassing, especially when you are not possessed of the capacity to cope with them.

Mr. W. S. Cramer: The speaker was particularly interested in Mr. Hill's reference to the effect of sewering cities and the increasing population with reference to increasing the per capita consumption. The experience in Lexington, Ky., was that in 1900, with 20 per cent of the city sewered, and with 96 per cent of our supply metered, the per capita consumption was 40 gallons; in 1912, with 40 per cent of the city sewered, with an all metered supply, the per capita consumption had risen to 60 gallons per capita.

Mr. H. C. Hodgkins: The first statement made by Mr. Hill, if the speaker remembers correctly, was that the distribution system would cost about 60 per cent of the entire cost of the plant. A rule of thumb that the speaker has used in the central west where the works consisted of a standpipe, no expensive reservoir, no filter plant, and in towns ranging from 10,000 to 20,000 population, was that as soon as he knew the tonnage and cost of iron pipe he would multiply the cost by 3 and so arrive at a result that was generally within a few thousands of dollars of the cost of the plant.

An experienced man frequently finds that his plant has become inefficient and too small in capacity; occasionally he may find that it is too large in capacity, when of course he is asked, "Why were you extravagant when you designed and built this plant?" In view of such experiences this paper is particularly *apropos*, and is excellent in its statement of fundamental principles and in the general directions given as to methods of procedure. But after all, these are simply for basing judgment and not an absolute rule; for instance: when the City of Toronto employed an engineer, in about 1906, and paid him what seemed to us in those days a very large fee, $15,000, he prepared an elaborate table to the effect that in 1940 the City of Toronto would have a population of 450,000. Before one-third of that time had elapsed the population had reached that figure, and it would be a very difficult matter to find anyone in Toronto now who does not believe that in 1940 it will have 1,000,000 population. So that the figures that he made up would under present conditions appear to be poor planning; yet the speaker does not think anyone will undertake to say that he did not use good judgment or that he was not well equipped for the work he had in hand.

The question of your pipe distribution becomes occasionally a very pertinent one; for instance: you find some systems where they pump directly into the mains; and where hydro-electric power is very cheap, and it is a proposition then of pumping with electrically driven turbine pumps directly into such a system. If Mr. Hill wants a real nut to crack, let him proportion such pumps to provide a high maximum load, and also for a minimum load, and see where he would come out.

Mr. W. C. Hawley: It would seem that with reference to the per capita consumption we must take into consideration the rate at which water is sold. If the quantity rate is high and the minimum rate small, there will be a minimum use of water, whereas much more water will be used, and leakage not watched closely when the minimum rate is such as to allow a liberal quantity of water, or when the quantity rate is low; and these conditions will have to be considered in all cases. It is difficult to do this because of the shifting of rates by our city councils without carefully studying the costs of furnishing the water.

Mr. J. M. Diven: Mr. Hill speaks of the contours. There are so many things we want to get on our distribution map that contour lines have been found greatly in the way and the speaker has adopted the practice of indicating the elevation of fire hydrants above datum in figures on the maps.

Mr. Hill spoke of the insurance maps getting out of date. These very convenient maps are now being kept up to date by the insurance people. A man comes around once a year to correct them. Slips with all changes are pasted over parts of the maps where changes have occurred.

Mr. N. S. Hill, Jr.: The author wants to make more clear the point that he wished to make in regard to Mr. Chester's comments on the paper. We all realize that in every community there are changes which cannot be foreseen; some of these changes are sudden, and in many instances they are directly opposite to the preconceived notions or the estimates of the engineer. It is manifestly impossible to prepare for the unexpected; nevertheless that fact should not in any way deter the water works engineer or water works superintendent from making the best possible future estimate

he is able to make with the data in hand. Failure to do so is a mistake. In the long run, if such estimates are made, notwithstanding the sudden conditions which may arise and have to be met from time to time, the total investment in the distribution system at the end of a given period will still be less. The speaker also believes that in many cases, if the local conditions of the community, the trend in adjacent communities, and the trend of development around the particular community, are noted, some conception may be had of the probabilities in the special community under consideration; at least a much more clear conception than would be arrived at by the mere haphazard method of laying pipe here and there, or in some other place, simply to meet such demand as eventuates. In all these estimates, such as a previous speaker brought up in the case of Toronto, all engineers are liable to error, and if we conducted all our business on the plan of refraining from expressing our opinions, and saying that we could not estimate because something unforeseen might happen, we would not go very far along the road toward progressive and intelligent designing.

Mr. P. Gear: The older men in our water works plants will all admit that thirty or forty years ago the water works engineers were not such specialists in water works practice as they are today. Perhaps there is now no class of engineers who are better prepared in their line of work than the water works engineers. When our distribution system was first laid out, the pipe arrangment was suitable enough for it, but with growth and development of our city our distribution system was necessarily expanded. For a number of years our commissioners did not consult any engineer as to the distribution system, but laid such mains as seemed desirable to themselves. However, our distribution system never failed us when it was called on in an emergency, although some of the pipes which were laid were later found to be too small, and had to be taken out. Our city is built on a bank of the river, so that there is no chance for growth except in one direction, and that is toward the reservoir, which helped our distribution system.